THE ANGSTREM PROJECT: PRESENT STATUS AND DEVELOPMENT ACTIVITIES

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Abstract

The project ANGSTREM of a modular-transportable nuclear power-and-heating station with assured safety for remote areas is described. The station is based on fast nuclear reactor cooling by a lead-bismuth eutectic. The possible evolution of the project is mentioned in relation to possible new application - sea water desalination or refrigeratory plants.

DESTINATION

The ANGSTREM Project is a modular-transportable nuclear power-and-heating station with assured safety for remote areas. The cooling of the primary circuit is a lead-bismuth eutectic (Pb is ~44%, Bi is ~56%) and several passive safety systems are included. EDB" Gidropress" is the main designer. IPPE is the scientific adviser of the Project.

The present status of the ANGSTREM Project is presented. The possible evolution of the ANGSTREM Project is mentioned in relation to a new application. It is possible to utilise the thermal power of the station to sea water desalination or to use it in refrigeratory plant.

DESIGN

The project was the first application of the 40 years experience of development and exploitation of lead-bismuth cooled reactors to small power level co-generation plants. It was the first attempt to realize the concept of inherently safe NPPs, in which the laws of nature principally exclude the accidents with severe consequences.

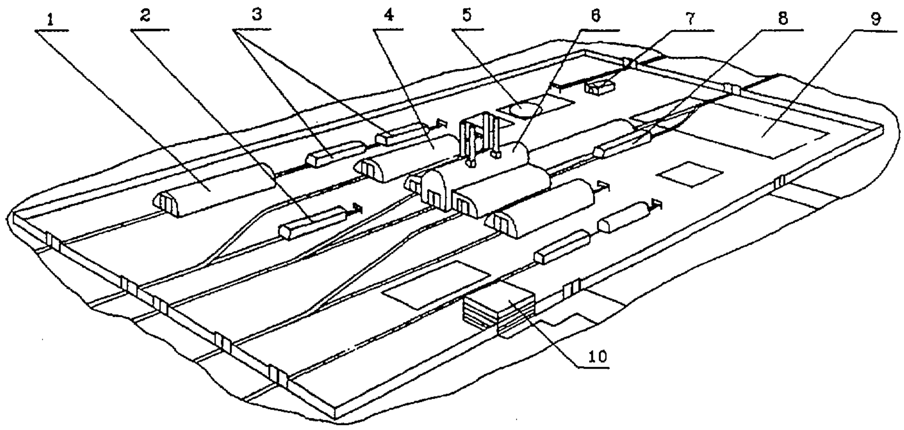
The station consists of:

- a set of buildings on the station site (shown in fig. 1).
- a set of functionally-finished, and completely factory-made modules in these buildings.

The modules can be delivered to the place of operation by all the kinds of transport. The development is in the stage of the detail engineering design. The project is based on the technical decisions which have been proved in practice. There are main equipment prototypes in service and commercial production.

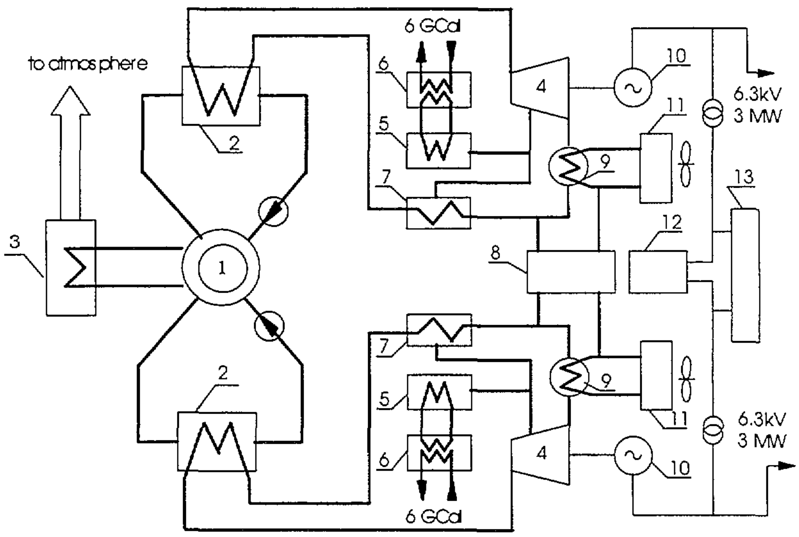
The ANGSTREM can be operated in the territories of increased seismicity, and aridity in climatic conditions from +40°C to -60°C. The reactor plant is a fast neutron reactor cooled by lead-bismuth in two-loops. The station nuclear fuel cycle is in harmony with the fuel cycle procedures of NPPs in current use. The station is equipped with a system of process automatic control and technical diagnostics, which provides safe operation and allows to minimize the operating personnel.

The project of the ANGSTREM station won the competition "Small Nuclear power stations-91" held by the Russian Federation Nuclear Society in the class of similar power level stations.



1 - Central control room compartment
2 - Water treatment system
3 - Cooling system
4 - Electrical switchgear device module
5 - Reservoir for fire-fighting water inventory
6 - Main building
7 - Storehouse for combustible materials
8 - Laboratory-workshop
9 - Supplementory territory
10 - Office building

Fig.1. Station general view.



1 - Reactor
2 - Steam generator
3 - Emergency cooldown passive system
4 - Turbine
5 - Heat exchanger for heat supply system
6 - Boiler
7 - Feedwater heater
8 - Water treatment
9 - Condenser
10 - Electrical generator
11 - Air radiator
12 - Reliable electric power supply system
13 - Ancillary power consumers

Fig.2. Station process diagram.

LEAD-BISMUTH COOLANT FEATURES

Over the long time of investigations, all principal problems related to utilizing lead-bismuth as a coolant in the NPPs were successfully solved: neutronic and thermal physics of the core, heat exchange and hydrodynamic characteristics, corrosion strengths of structural materials and coolant quality, radiation and nuclear safety, study of accident situations, development of fuel and absorbing elements, equipment of the primary circuit, etc. The intensive experimental base was founded which is equipped with unique test facilities.

A lead-bismuth coolant has a number of important safety features:

- Low margin of potential energy excludes the possibility of thermal explosion of the reactor under the internal pressure forces even at very high temperatures. It prevents the loss of coolant due to exclusion of the coolant evaporation by boiling (as it takes place with water coolant) or its blowdown under pressure (as with gas coolant).
- It has high boiling point (1670°C under atmospheric pressure) that eliminates the possibility of DNB occurence, that increase the reliability of the heat removal from the core. It allows to reach high process parameters of the secondary circuit and the high efficiency of the thermodynamic cycle under the low primary pressure.
- Low freezing-point of lead-bismuth (125°C) makes possible to decrease (or exclude by appropriate design) the possibility of the loss of coolant caused by primary leakages.
- Small coolant volume shrinkage on solidification (~1.5 %) and rather high plasticity prevent damages of the primary equipment at the controlled transition of the coolant from liquid to solid states and its cooling to the ambient temperature. This feature can be used for safe handling of the fresh or the spent core, against potential accidents during transportation.
- Low chemical activity eliminates the possibility of fires and explosions in the event of coolant leakages into the reactor room or the liquid metal-water reaction due to the steam generator tube ruptures.
- Low induced long-lived gamma-activity of the coolant and its property to retain iodine and other radionuclides considerably simplify the radiation situation under the primary leak conditions. About in a day after the reactor shutdown the dose rate of gamma-radiation on the outer surface of the primary equipment lowers to the level facilitating to perfom its examination and repair without over-exposure of the personnel.
- Low interaction with neutrons provides the high conversion ratio which allows considerably decrease the burn-up reactivity depletion and extend the core life cycle.
- The reactivity effects of lead-bismuth coolant (void, power, temperature) is negative.

SAFETY

The nuclear power-and-heating station is designed according to the defence-in-depth approach to protect personnel and population. It assumes that the system of barriers is provided on the way of propagation of ionizing radiation and radioactive substances into the environment. Also it includes the technical systems and the organizational measures to ensure the efficiency of these barriers in case of an accident.

The station system of barriers includes:

- fuel matrix;
- fuel rod cladding;
- primary circuit with gas system;
- reactor module hermetic compartment;
- external radiation shield;
- protective guard of the station.

The defence-in-depth approach in the multi-barrier system provides protection of barriers themselves, each of them being protected by the subsequent one. The last barrier - the station protection guard - is designed to withstand the extreme external events:

- earthquakes;
- airplain crashes;
- shock waves.

The nuclear power-and-heating station safety is based on the reactor inherent safety features, utilization of the safety systems and conservative approach in the design and safety analysis. The reliability of heat removal systems should be especially underlined. There are:

- ordinary heat removal systems - secondary circuit, SG and turbogenerator;
- emergency heat removal system - in the loss of feedwater accident, the water inventory in the separators can be utilized for heat removal to the air condenser under natural convection;
- passive heat removal system - always in service.

ECONOMIC ASPECTS

The competitiveness of small scale NPP in comparison with large scale ones can be accomplished, in spite of downsizing, under the following conditions:

- the number of systems should be strongly reduced;
- the specific mass of steel should not be increased; and
- the specific operation and maitainance cost should not become excessive.

These targets are achieved for the ANGSTREM NPP by means of:

- all the NPP modules are functionally-finished, and completely factory-made;
- minimum buildings to be constructed at the NPP site;
- no high and large buildings ligthens the foundation loading and the plant can be built on the seabeach, the soft soil, the seismic area and so on;
- the construction time is reduced to one year;
- partial reloading is excluded to minimize the operation cost; and
- the core lifetime considerably prolonged;
- low decomissioning cost;
- the environment around the plant would not be polluted in any accidents.

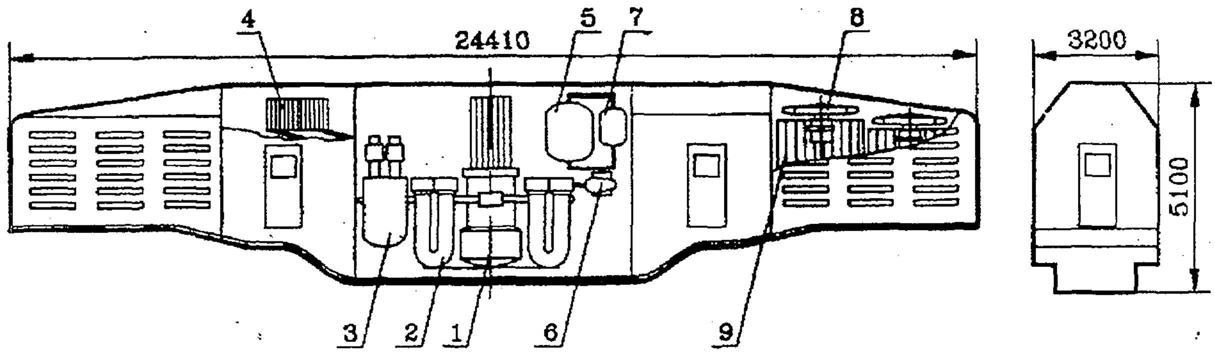
MAIN PERFORMANCES

Name	Value		Remark
Thermal power	30	MWth	
Core inlet temperature	290	^0C	
Core outlet temperature	465	^0C	
Feedwater temperature	190	^0C	
Steam pressure	3.5	MPa	
Steam flow rate	55	t/h	
Steam outlet temperature	435	^0C	
Core size: diameter	0.79	m	
fuel length	0.7	m	full length 1.9 m
Fuel cladding material	SS		stainless steel with 13% Cr and 1% Ni
Fuel cladding diameter and thickness	12 × 0.4	mm	
Fuel	UO_2		
Maximum fuel burnup	8.6	%	average — 6 %
Mean makeup fuel enrichment	26	%	
Mean volume power density	87	MW/m^3	
Mean linear fuel rod power	17	kW/m	
Electric power, net	6	MWe	
Heat supply power	up to 14	MWth	temperature condition of heat-supply system is 130 / 70°C
Possible desalination capacity	~445	m^3/h	
Possible refrigerating capacity	~10	MWth	production of ~2°C cold water
NPP Lifetime	30	years	
Safe shutdown earthquake	9		magnitude as per scale MSK-64
Load follow rate	up to 1	% per sec	
Core lifetime	70 000	eff. Hour	refuelling in ~ 10-15 years
Number of operating personnel	26	persons	for 5 shifts
Number of station modules	9-12	pieces	depending on water resourses
Mass of modules	60-220	ton	
Frequency of scheduled preventive repairs	8000	h	once a year
Starting-standby source	diesel-generator		500 kWe
Cost for preparation for mastering	75	mln US $	Far North
the commercial station	53	mln US $	Center
Cost of the commercial station	26	mln US $	33 mln US $ with the desalinated water equipment
Annual operational expenses	3-4	mln US $	with account of fuel
Prime cost of energy:			
-electrical	0.08	US $ / kWh	
-heat	11	US $ / Gcal	
-desalinated water	0.9	US $ / m^3	
Radius of sanitary-protective area	1.0	km	

DESCRIPTION OF THE MODULES

Steam supply system module

The reactor and the heat transport system are mounted on the steam supply system module. The module compartment is hermetic. The module design allows the core to be reloaded in the site or to be transported to the Special Operation Base for refuelling. The core lifetime is about 10-15 years depending on the operation power level. The Module can be exploited alone and the reactor heat can be removed under any conditions.

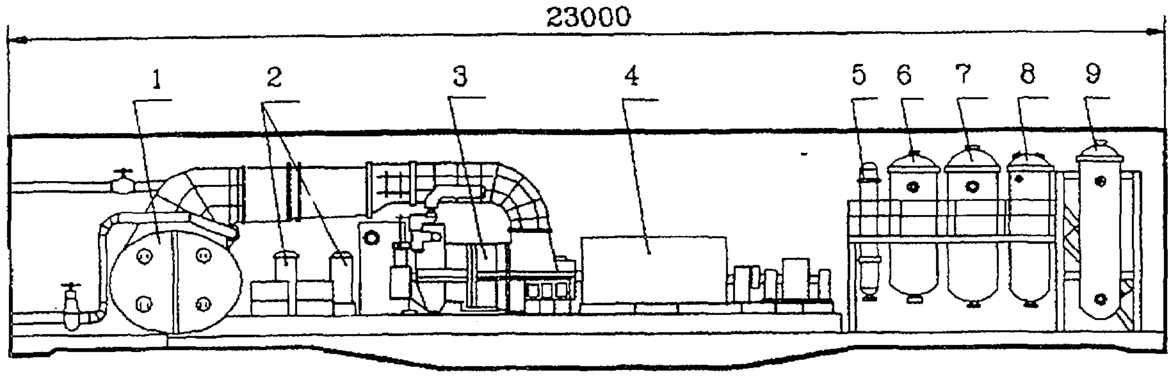


1 - Reactor	4 - Radiator of heat tubes	7 - Cooldown condenser
2 - Steam generator	5 - Separator	8 - Fan
3 - Pumps tank	6 - Controlled circulation pump	9 - Cooling radiator

Fig. 3. Steam supply system.

Turbogenerator module

There are two turbogenerator modules in the ANGSTREM plant. The module includes a turbine, a generator, a condenser and a number of heat exchangers. To increase the district heating (or desalination) capacity up to 20 MWth the backpressure turbine can be used.

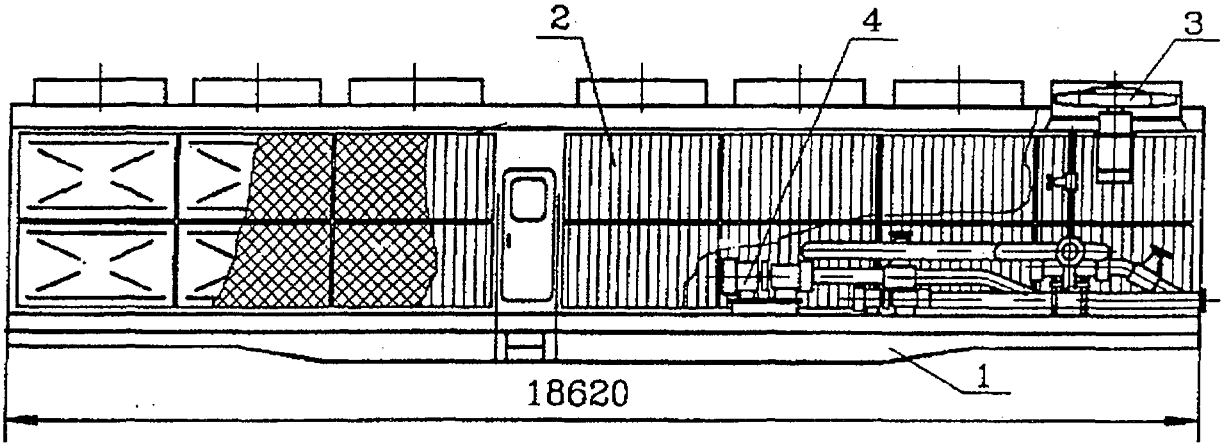


1 - Condenser	4 - Electric generator	7 - High temperature filter
2 - Oil cooler	5 - Low pressure heater	8 - High pressure heater
3 - Turbine	6 - Ion exchanger	9 - Heat exchanger for heat supply system

Fig. 4. Turbogenerator module.

Central control room module

The NPP is controlled from the Central control room module. The module is located in a separate compartment.

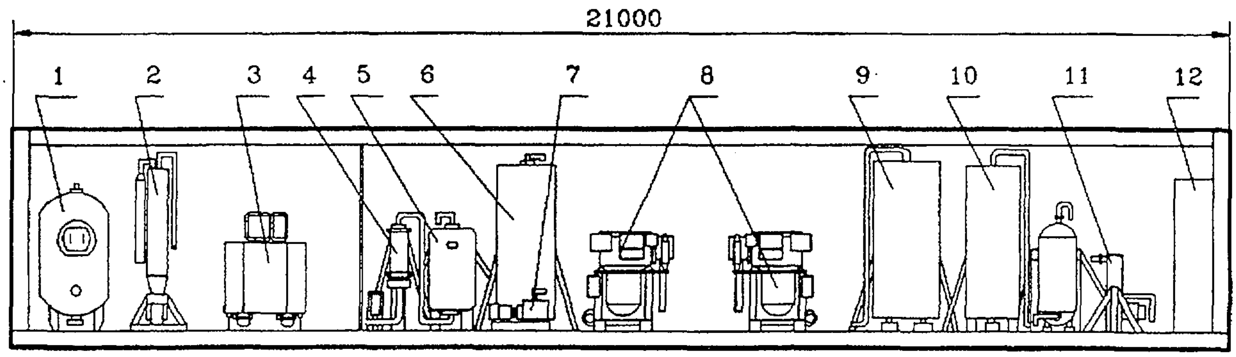


1 - Platform 2 - Air radiator unit 3 - Fan 4 - Electric pump

Fig. 5. Air radiator module.

Air radiator module

There are four air radiator modules in the ANGSTREM plant. The module is designed for the tertiary circuit water cooling. The tertiary circuit water removes the heat of main condensers. When the backpressure turbine is applied, the number of these modules can be reduced to one. Also these modules can be used for remote air-conditioning systems of consumers.

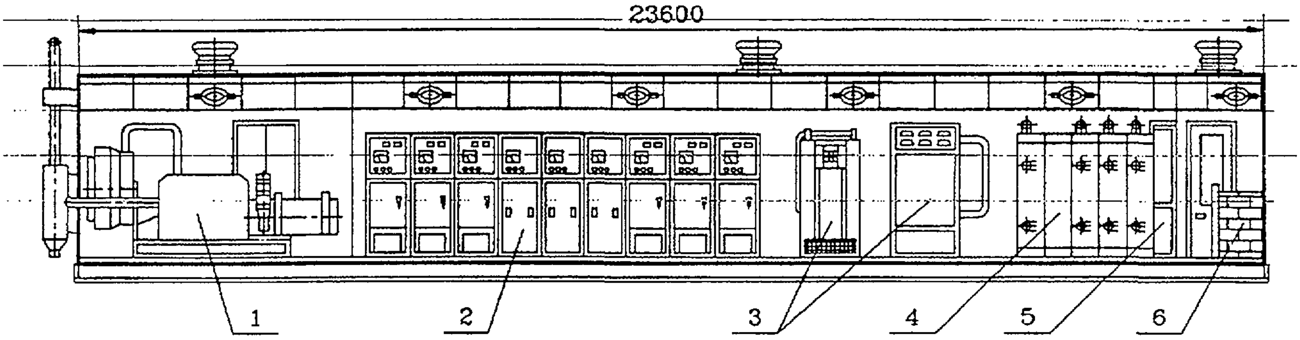


1 - Mechanical filter
2 - Mixing device
3 - Ozonizing device
4 - Electrical coagulator
5 - Clarifying filter
6 - Clarifyed water inventory tank
7 - Pump
8 - Water desalinating distillate plant
9 - Distillate inventory tank
10- Potable inventory tank
11- Water bactericide treatment plant
12- Instrumentation control pannel

Fig. 6. Water treatment module.

Auxiliary modules

The auxiliary modules are: the water treatment module, the electric switchgear device module, and the laboratory-workshop module.



1 - Diesel-generator
2 - Switchgear 6.3 kV
3 - Transformer substation 0.4 kW
4 - Uninterrupted supply set
5 - Reliable power supply switchgear
6 - Battery

Fig. 7. Electric switchgear device module.

CONCLUSION

The ANGSTREM modular-transportable nuclear power-and-heating station is based on experience of the nuclear power reactors for submarines. The main features are: compact reactor layout associated with functionally-finished, completely factory made modules; and the flexible reactor concept for co-generating electricity and heat for district heating or sea water desalination. The economic competitiveness can be made possible by the modular solution and the low sensitivity to downsizing.