NUCLEAR FLOATING POWER DESALINATION COMPLEXES

Y.K. PANOV, V.I. POLUNICHEV
OKB Mechanical Engineering,
Nizhny Novgorod

K.V. ZVEREV
Ministry of the Russian Federation for Atomic Energy,
Moscow

Russian Federation

Abstract

Russia is a single country in the world which possesses a powerful ice-breaker transport fleet that allows a solution of important social-economic tasks of the country's northern regions by maintaining a year-round navigation along the Arctic sea route. A total operating record of the marine nuclear reactors up until till now exceeds 150 reactor-years, with their main equipment operating life reacning 120 thousand hours. Design and constructional progresses have been made continuously during forty years of nuclear-powered ships construction in Russia. Well proven technology of all components experienced in the marine nuclear reactors give grounds to recommend marine NSSSs of KLT-40 type as energy sources for the heat and power co-generation plants and the sea water desalination complexes, particularly as a floating installation. Co-generation stations are considered for deployment in the extreme Northern Region of Russia. Nuclear floating desalination complexes can be used for drinkable water production in the coastal regions of Northern Africa, the Near East, India etc.

1. Marine nuclear reactors creation and operation experience in Russia

Russia is a single country in the world which possesses a powerful ice-breaker transport fleet that allows a solution of important social-economic tasks of the country's northern regions by maintaining a year-round navigation along the Arctic sea route. The first nuclear ice-breaker "Lenin" was launched in 1956 and commissioned in 1959 as a vessel registered to the Murmansk shipping company.

This year (1997) navigation is the 38th year of navigation in the history of the Russian civil nuclear-powered fleet which consists of seven nuclear ice-breakers and one transport (lighter carrier) ship (Fig.1). The fleet's forefather, the ice-breaker "Lenin," has already retired from operation, while a construction of the latest ice-breaker "50th Anniversary of Victory" is approaching completion now. Main performance indicators of the nuclear-powered ships over the period from 1970 till 1995 are given in Table I.

The total operating record of the marine nuclear reactors under heavy duty conditions (rolling, vibrations, impacts of ice-floes, frequent maneuvering) has exceeded now 150 reactor-years, while that for main equipment items on operating reactors has reached 120 thousand hours. During that period no incidents associated with the chain reaction control violation or the unallowable release of radioactivity have been indicated.

While experience has been accumulated over many years in Russia in the field of marine reactor plant design and construction, cooperation of many participating enterprises has been established. Appropriate infrastructures have been developed to provide maintenance and repair work of nuclear-powered ships at the base of the Murmansk shipping company.

Proven technology and high operational reliability of the ice-breaker reactor plants are achieved mainly by the fact that those plants were developed and constructed for many years by the same enterprises and shipbuilding works that have been constructing nuclear propulsion plants for the Navy

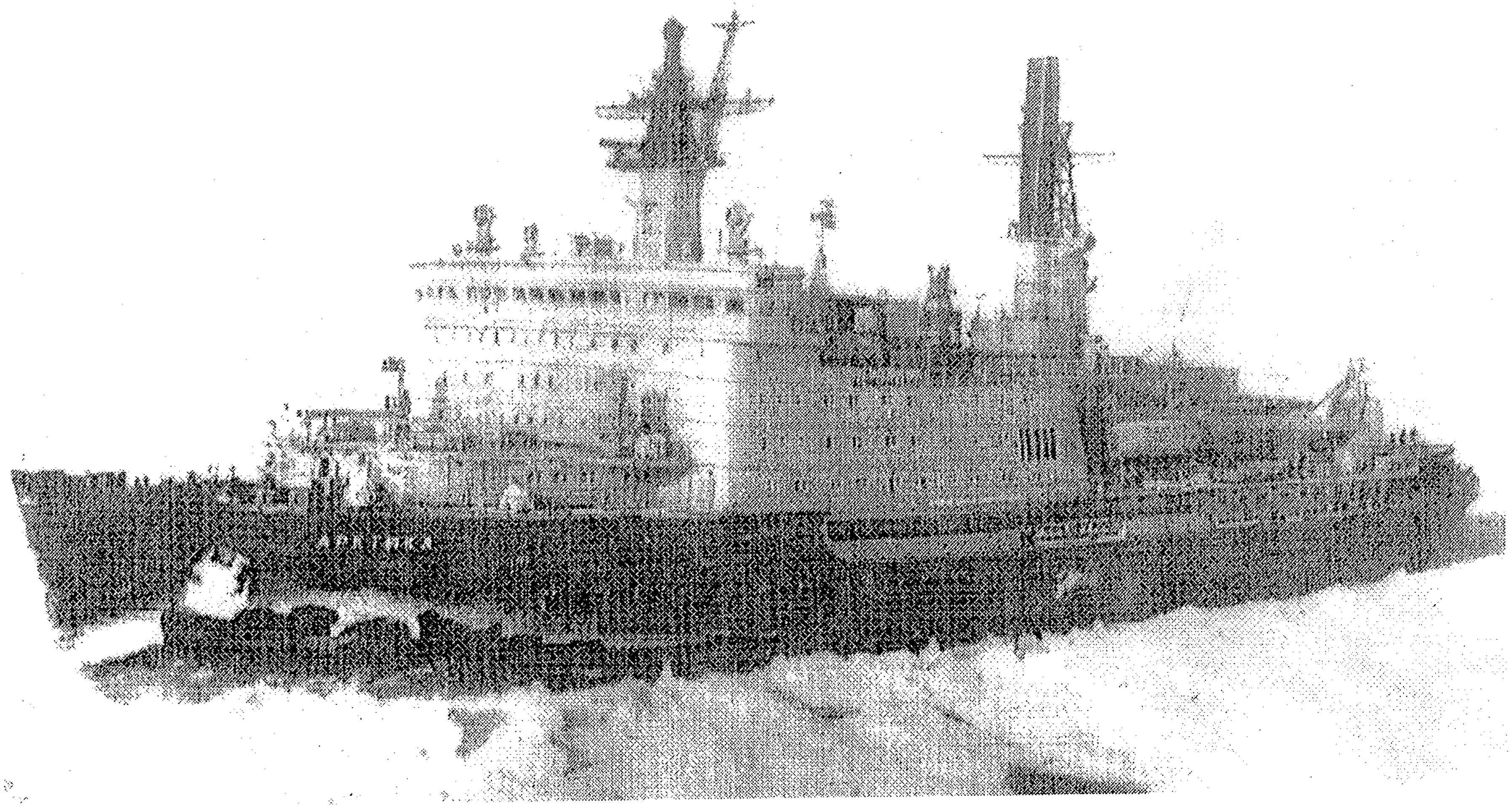


Fig. 1- Nuclear ice-breaker "Arctica" conducting transport ships on the Polar sea route

Table I Nuclear-powered ships performance indicators over the period from 1970 till 1995

Characteristics	Name of ship									
	i.-br. "Lenin"	i.-br. "Arctica"	i.-br. "Sibir"	i.-br. "Russia"	i.-br. "Sov. Souz"	i.-br. "Taymir"	i.-br. "Vaygach"	i.-br. "Yamal"	l.-cr. "Sev-morput"	i.-br. "50th celebration of Victory"
1. Year of commissioning	1970	1974	1977	1985	1989	1989	1990	1992	1988	under construc-tion
2. Averaged duration of operation per year, days	230	225	232	258	232	255	252		291	
3. Total reactor operating record from power start-up, h	106740 106350	**117643*** **118661**	94785 94043	60572 60011	40021 39775	43299	36755	23219 22976	48161	
4. Total energy produced from power start-up, 10^3 MW·h	6523 6398	**7756*** **7244**	6095 6933	4294 4472	2243 2668	3453	2754	1329 1321	2756	
5. Distance sailed, miles										
1) total;	654400	744478	740786	391761	221993	247516	126057	143539	198537	
2) incl. through ice	560600	649497	472787	361283	183572	230817	96597	131634	10885	
6. Number of ships conducted	3700	2645	1711	1121	300	627	137	445		

Notes: *** - on 01.01.1997**
i.-br. - ice-breaker
l.-cr. - lighter-carrier

(submarines and surface warships). Most advanced machine - and ship - building technologies were always available there. Therefore the nuclear-powered civil ships were from the very beginning an effective line in the conversion of the defence technologies.

There are various grounds to recommend the marine nuclear reactors as advanced heat sources for floating sea water desalination complexes. They are application of advanced constructional and technological provisions, *continuous* perfection of safety systems to meet updated regulatory requirements for nuclear safety and improvement of equipment items based on operational experience feedbacks.

Drinkable water production became one of the acute problems for many regions of the world, e.g. Northern Africa, Near East, India etc. Also in northern regions of Russia drinkable water has high cost. Extensive work on assessing a potential of economical and efficient utilization of nuclear energy for sea water desalination is currently being conducted under the IAEA umbrella. The former USSR was a leading country in nuclear energy utilization for that purpose (e.g. the nuclear power-desalination complex with the fast reactor BN-350 has been operating since 1973 in Aktau on the eastern coast of the Caspian sea, Kazakhstan). Among a number of different configurations, IAEA's consideration includes a floating power-desalination complex, using a marine nuclear reactor plant of KLT-40 type and the desalination facilities of distillation and reverse-osmosis processes.

Main advantages of nuclear floating desalination complexes are as follows:

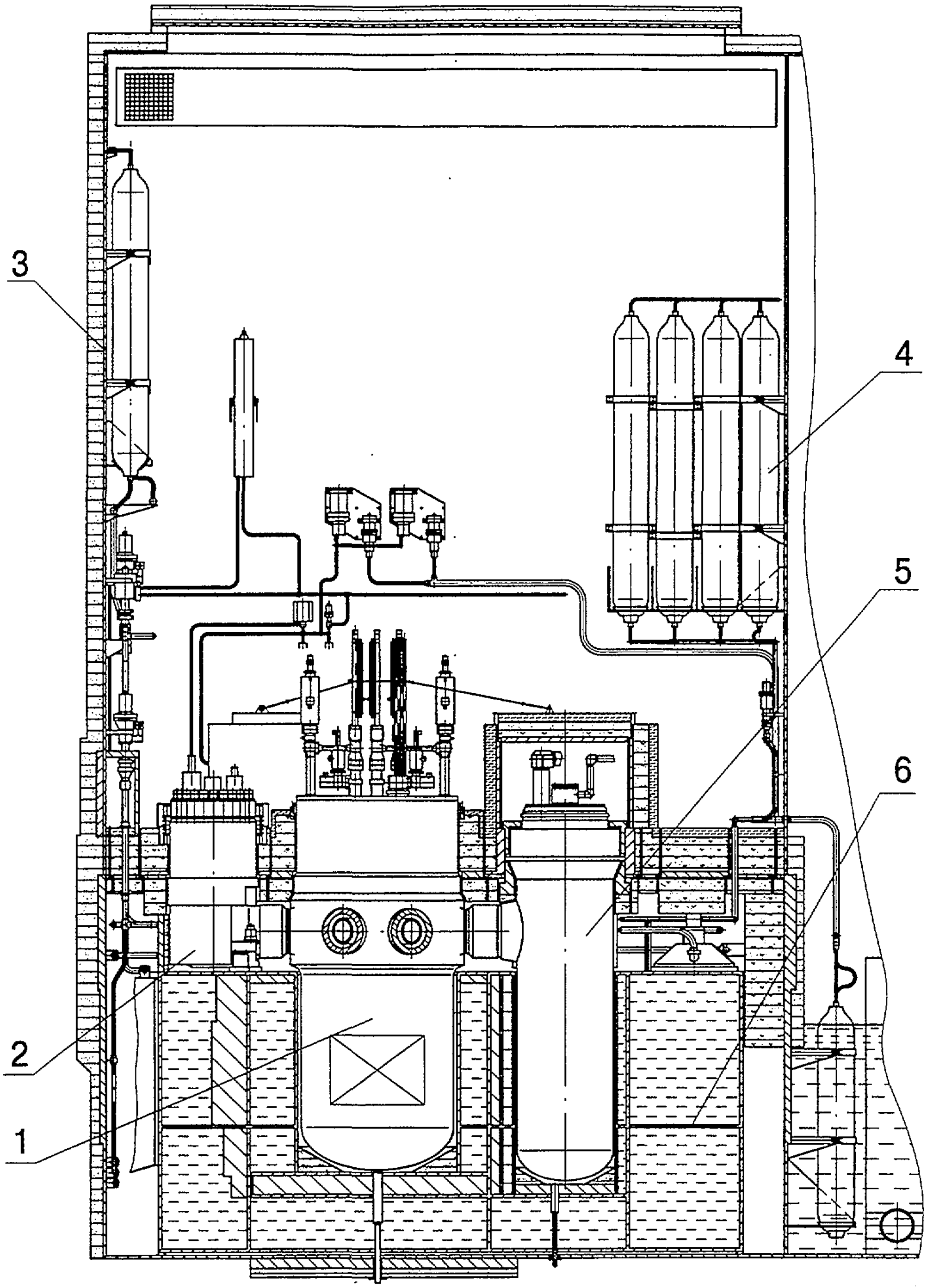
1) high quality of the entire floating power unit fabrications under specialized shipbuilding works conditions followed by delivery to the customer on a turn-key basis;
2) reduction of a station construction period to 4-5 years and of investments as compared with land-base NPPs;
3) a potential for siting at any coastal regions;
4) simplification of antiseismic design measures;
5) cost reduction by serially-produced reactor plants; and
6) simplicity of FNPP decommissioning technology, etc.

Distillation facilities are approximately designed in Russia by the SverdNIIChimMash Institute (Sverdlovsk), while the reverse-osmosis facilities are produced by the Canadian firm "Candesal Inc." A Memorandum of understanding was signed in 1995 and extended in 1997 between "Candesal Inc." and "Russian Ministry of atomic energy (MinAtom)" on the joint design of a desalination complex. At present, potential approaches to an acceptable investment in the project are under consideration, as well as its specific technical aspects.

2. Marine nuclear reactor plant of KLT-40 type

2.1. Technical concept

PWRs which are most widely experienced in the world and their reactor technologies are well proven. KLT-40 is implementing their practice. The plant equipment, i.e., a nuclear reactor, steam generators and reactor coolant pumps are accommodated in a steam-generating unit by short pressure nozzles. The reactor plant is enclosed in a protective shell (containment) designed for a pressure which could emerge as a result of the loss-of-integrity accident of the primary system (Fig.2). The protective shell is housed in a protective enclosure which provides the reactor plant with the protection barrier against the external hazards, like an aircraft crash, a collision with other ship, blast wave impacts, etc.



1- reactor

2- reactor coolant pump

3- protective shell

4- gas cylinders

5- steam generators

6- steam-water shielding tank.

Fig. 2 - KLT-40 nuclear reactor plant

2.2. Safety

The KLT-40-type reactor plant is being designed in conformity with the modern regulatory documentation for nuclear safety (OPB-88, PBYa RU AS-89 etc.). The physical properties of the reactor core (negative reactivity coefficients for power, fuel and coolant temperatures) with a current heat removal capacity maintain the power under self-control without interventions of reactivity control personnel, and the power is self-limited without the aid of the emergency protection system (Vorobiev, 1989).

High heat capacity of the primary coolant and metalwork in combination with the passive residual heat removal system provides an ample time margin for management of hypothetical accidents with complete loss of engineered heat removal means.

Redundant active and passive protective systems are provided for the reactor plant. The inherent self-protection properties of the reactor, and the extensive application of passive and self-actuated safety devices provide the reactor with resistivity against human errors and equipment failures. The reactor plant is equipped with a sophisticated technical diagnostic system.

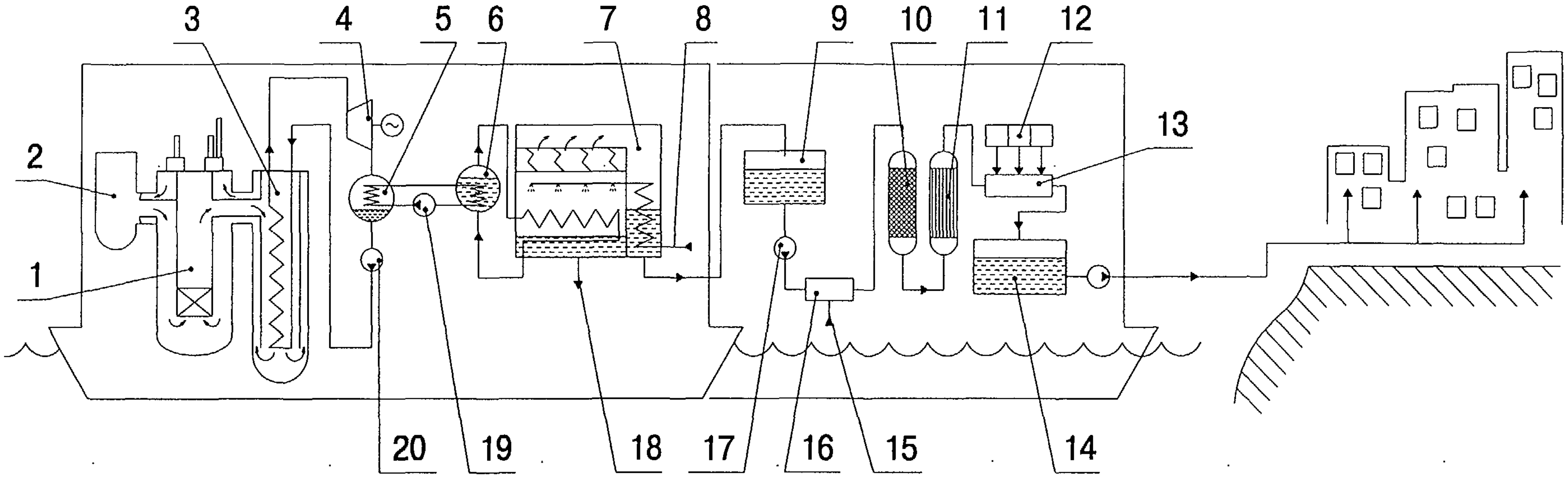
The leak-tight arrangement of the reactor plant prevents releases of noticeable amonunt of radioactive substances during normal operations and accidents. According to the available marine reactor operating experience, small release of radioactivity is conditioned mainly during refueling operations and by air activation under a primary biological shielding.

The exposure dose to an inhabitant at a distance of 1km under normal operation conditions is about 0.01mrem per year. The available systems for radiological safety provision and a multi-barrier system for radioactivity containment limits effectively the radiological consequences of accidents. The population evacuation is not necessary in accidents. Engineering measures in the design, and the enhanced safety corroborated by the multi-year operating experience let the plant to be deployed in the close vicinity of settlements.

Basic design characteristics of the reactor plant are given in Table II.

Table II KLT-40 NSSS basic characteristics

Thermal power, MW (th)	148
Steam flow, t/h	240
Core operating life, h	14600
Refueling interval, yr.	2.5-3
Primary system pressure, MPa	12.7
Core outlet temperature, °C	317
Steam pressure, MPa	3.72
Superheated steam temperature, °C	290
Feed-water temperature, °C	170
Power variation range, %Nnom	10-100
Continuous operation duration, h	8000
Service life, yr.	40



1- reactor
2- primary circuit circulator
3- steam generator
4- turbo-generator
5- condenser
6- steam generator
7- distillation desalination plant
8- sea water inlet
9- distillate intake tank
10- water enrichment facility
11- powdered sorbent filter
12- plant for water fluorination, chlorination and stabilization
13- mixer
14- potable water tank
15- H_2CO_3 solution
16- mixer
17- potable water preparation plant electric pump
18- evaporated sea water brain
19- intermediate circuit electric pump
20- secondary circuit electric pump

Fig. 3- Principal flow diagram of the station with thermal desalination

Table III Basic technico-economic characteristics of floating sea water desalination station

Length of vessel, m	160
Width of vessel (max.), m	44
Draught, m	7
Drinkable water output, m^3/day	80000
Service life, yr.	up to 40
Number of reactors	2
Number of desalination facilities	4
Refueling interval, yr.	2-3
Average load factor	up to 0.85
Staff, persons	60
Term of pilot station creation, yr.	ab. 5
Cost of pilot station creation, million USD	up to 300
Average operation cost per year, million USD	50-60
Cost of 1 m^3 water, USD, not more	2.5
Recoupment period, yr.	8-10

3. Floating water desalination stations

Two options of a floating water desalination station design have been developed: with a distillation desalination facility and with a reverse-osmosis one.

3.1. Floating station for sea water desalination using distillation technology

The station is a special non-self-propelled vessel mounting two nuclear reactor units of the KLT-40-type intended for sea water desalination to be operated under conditions of a protected sea area in combination with a respective land-based support areas at the station destination.

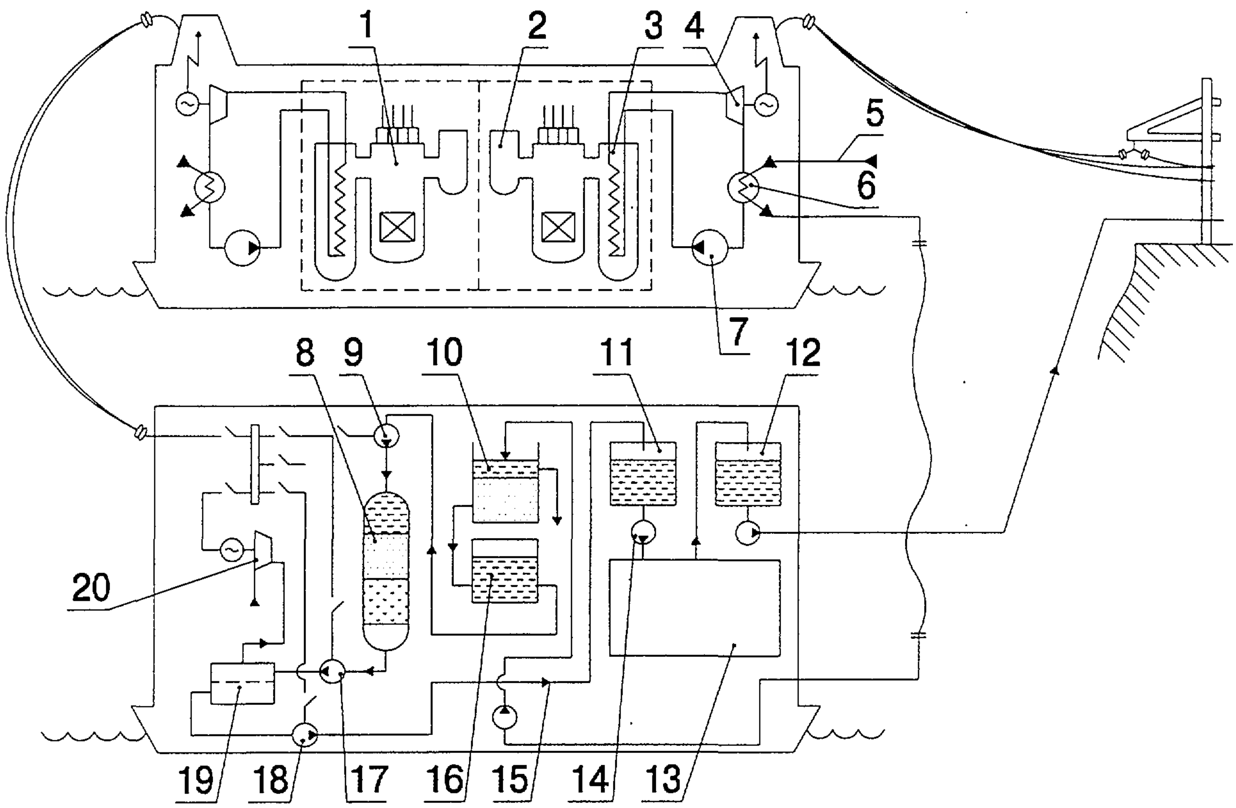
Two reactor units with a rated power of 80MW(th) work on two main turbogenerators with back-pressure turbines (Polunichev, 1995). Waste heat from the turbine condensers is transferred via an intermediate circuit to a twin-unit distillation desalination facility (Fig.3). The desalination unit composes of film evaporators with horizontal tube bundles. Similar evaporators have been successfully operated for many years in the nuclear power-desalination complex at Acktau (Kazakhstan) and at some other sites (Chernozoobov, 1955).

Engineering measures in the design eliminate completely the influence upon the sea and the desalinated water by the reactor unitss. Relatively small quantity of discharged heat during the station operation does not influence the environment.

Basic technico-economic characteristics of the station are given in Table III.

3.2. Floating station for sea water desalination using reverse-osmosis technology

The station is composed of two floating structures: an FNPP with two reactor units of KLT-40 and a vessel for the sea water desalination facility. Part of electricity generated by the FNPP is transmitted to the desalinator vessel to produce drinkable water, and the remainder is directed to the coastal consumers (Fig.4).



1- reactor

2- primary circuit circulating pump

3- steam generator

4- turbo-generator

5- sea water

6- condenser

7- secondary circuit electric pump

8- twin-layer pressure filter

9- booster pump

10- gravity filter

11- filtrate intake tank

12- potable water storage tank

13- potable water preparation unit

14- potable water preparation system electric pum

15- filtrate

16- clarified water tank

17- high pressure pump

18- fresh water pump

19- reverse osmosis module

20- hydroturbine

Fig. 4 - Principal flow diagram of the complex

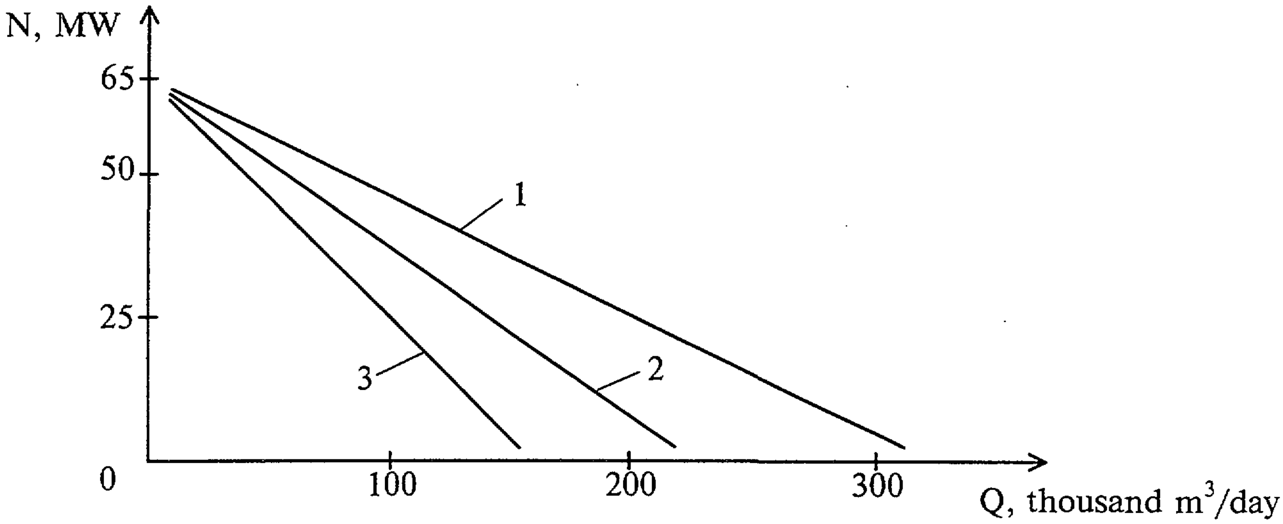


Fig. 5 - Excessive electric power (N) versus desalinated water output (Q) at given thermal power of reactors

1, 2, 3 - specific consumption of power per 1 m^3 of desalinated water - 5, 7, 10 kW.h respectively

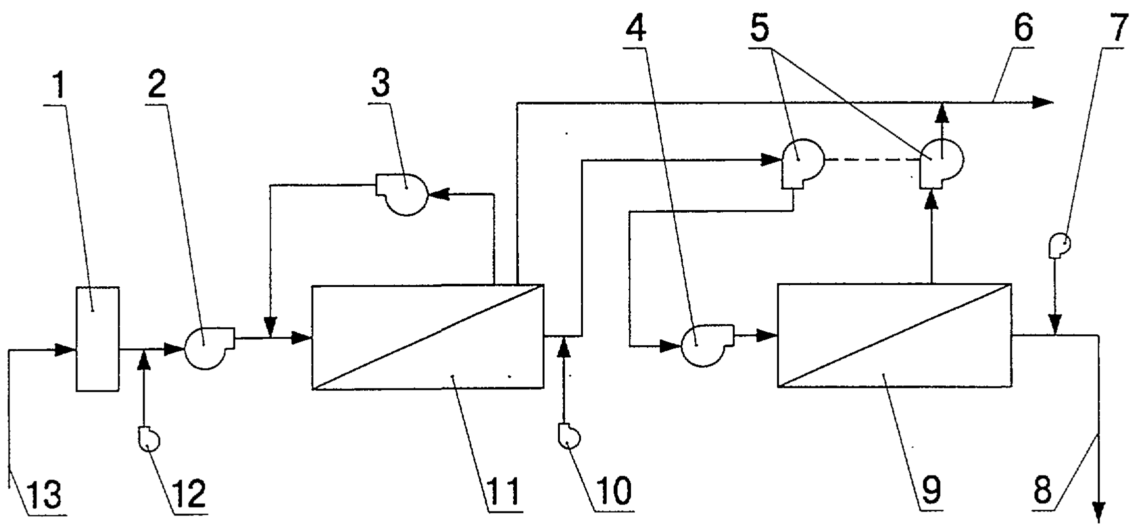
In order to optimize the station for technico-economic performances, different energy allocation can be made between the power and the drinkable water production at the given thermal power of the reactor plants of 2 x 150 MW (th). Possible options of power to drinkable water output relationships are given on Fig.5.

A time span of a pilot station construction is about 5 years, and its investment cost is about 300 million US dollars. One cubic meter of desalinated water will cost about 1 to 1.5 US dollars when the station is operated in a desalination mode.

Membranes which are capable of reducing the salt content from 39-43 g/l (sea water) down to 500 mg/l (distillate) are supposed to be used in the reverse-osmosis desalination facility.

Significant progress in development of reverse-osmosis desalination technologies has been attained by the Canadian firm "Candesal Inc.". The firm envisages implementing the latest sea water desalination technology which reduces significantly both a specific energy consumption for the desalination process and the cost of drinkable water produced (Hamphries, 1995).

The RO system design is based on spiral wound Dow Film Tec high rejection membranes for seawater desalination. Sea water discharged from the reactor's condenser cooling water system at a temperature of 10 ^{O}C above the ambient seawater temperature is used as feedwater for the system. The water first passes through ultrafiltration (UF) pretreatment modules. The filtrate from the UF units is sent to the capacitance tanks, from which suction is taken for the RO modules as feedwater. The feedwater is pumped up to high pressure (1000 psi) and then passes through the RO modules. The permeate from the RO membranes is delivered temporarily into potable water storage tanks, and from there transferred to an off-ship distribution system. Brine concentrate from the RO system is discharged back into the sea. Chemical pretreatment and post-treatment systems for feedwater and product water can be installed as needed (Fig.6).



1- pre-filter
2- medium pressure pump
3- reinculation pump
4- high pressure pump
5- energy recovery system
6- to external consumers
7- chemical additives inlet
8- potable water outlet
9- reverse osmosis membranes
10- anti-fouling additive injection system
11- ultrafiltration membranes
12- prelimiary chemical treatment system
13- sea water inlet

Fig. 6 - Simplified flow diagram of UF/RO desalination system

4. Work organization and financing

Available well proven technologies in the fields of marine nuclear reactors and desalination facilities, their established serial fabrication capabilities, solid experience in their mounting and operation, existing potential of Russian industries and established cooperation of scientific, design and industrial organizations in Russia - all these give the real guarantees of high quality and short term delivery of the station construction (not more 4 to 5 years for a pilot one) and would settle financing issues.

Following options of cooperation in constructing desalination complexes can be possible:

1) Construction of the station by Russian industries with possible participation of foreign and home investors with subsequent repayment of credits during the station recoupment period through sales of electricity or drinkable water produced. If applicable, regional resources (e.g. oil, natural gas, nickel, gold etc.) might be involved in the project investment structure.

   In the present project at Pevek, a pilot FNPP is being financed by the "Rosenergoatom" Concern (a Russian NPPs operator) at the expense of the state budget and loans (about a half of the total investment cost) which may be rendered by home and foreign investors. In this case the station will be a property of Russia.

2) Joint international venture incorporating potential executors and customers (consumers) with shared financing of the project and repayment of investments during the station recoupment period. In this case the floating station would be a property of all participants involved, while Russia will be a designer, vendor and owner of the nuclear reactor plant.

REFERENCES

[1] V.B. Chernozoobov, N.K. Tockmantsev, Y.V. Putilin (RF). From the experience of development and exploration of large distillation desalination facilities. IAEA Technical Committee Meeting. May 1995, Obninsk, Russia.

[2] I.R. Humphries, K. Davies (Canada). A Floating Generation System Using the Russian KLT-40 Reactor and Canadian Reverse-Osmosis Water Purification Technology. IAEA Technical Committee Meeting. May 1995, Obninsk, Russia.

[3] V.I. Polunichev, Y.A. Sergeev (RF). Choise of Thermal Scheme for Coupling Power and Low Temperature Nuclear Reactors with Desalination Plants. IAEA Technical Committee Meeting. 1995, Vienna.

[4] V. Vorobiev, N. Rodionov (RF). Safety of nuclear power plant. - Morskoy flot (magazine), [1].10-11, 1989 (in Russian).