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FLOATING NUCLEAR POWER STATION OF APWS-80 TYPE FOR ELECTRICITY GENERATION AND FRESH WATER PRODUCTION

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Abstract

To solve the problem of seawater desalination and electric energy generation, the designing organizations of Russia have developed two variants of floating nuclear desalination plant. The KLT-40 type reactor, with maximum 160 MW thermal power, is used as the power source for such plant. Depending on the customer requirement one or two power unit could be installed in the floating desalination plant. There are APWS-80 with two reactors, producing 80 000 m³ desalinated water per day and APWS-40 with one reactor, producing 40 000 m³ desalinated water per day. The advantages of floating desalination plants are the possibility to build and test them at the ship-build plant of the supplier country and to hand them over on turnkey base.

1. INTRODUCTION

For seawater desalination and electricity generation Russian design organizations have developed and can supply to Customers floating nuclear power/desalination stations based on the KLT-40 type reactor plant (Fig. 1). These plants meet international safety requirements for marine nuclear power plants (NPPs) and the requirements of Russian regulatory codes for NPPs including IAEA recommendations.

Main Reactor Plant Data

Thermal power, MW	up to 160
Steam capacity, t/h	up to 260
Steam temperature, °C	up to 300
Steam pressure, MPa	up to 4

The KLT-40 reactor has been successfully operated for many years in Russian nuclear ships and has been modified for each new ship generation based on accumulated experience.

The KLT-40 reactor plant was the winner among plants of the same power level at a competition "Small Nuclear Power Stations-91" held by the Russian Federation Nuclear Society.

Depending on customer requirements, the power/desalination station may be a one-reactor (APWS-40 type) or a two-reactor (APWS-80 type) design, hence the reactor thermal power is within 80 - 160 MW. Advantages of floating power/desalination complexes are:

- convenient maintenance by a floating base at a mooring site and decommissioning by tugging to the Supplier's country;
- commercial production and long-term confirmation of service life characteristics of the KLT-40-type reactor plants and desalination units;

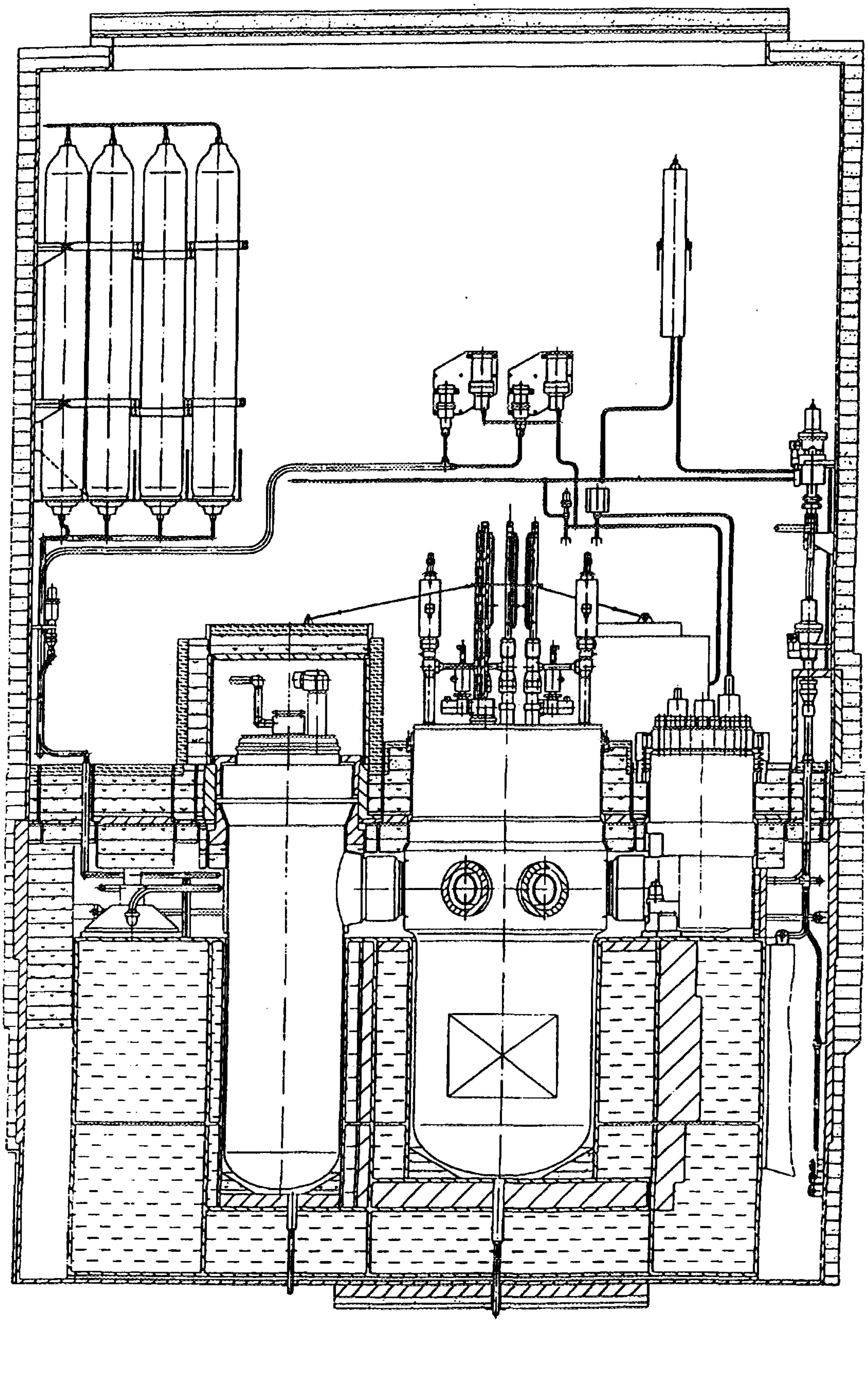


Fig. 1a. KLT-40 reactor plant.

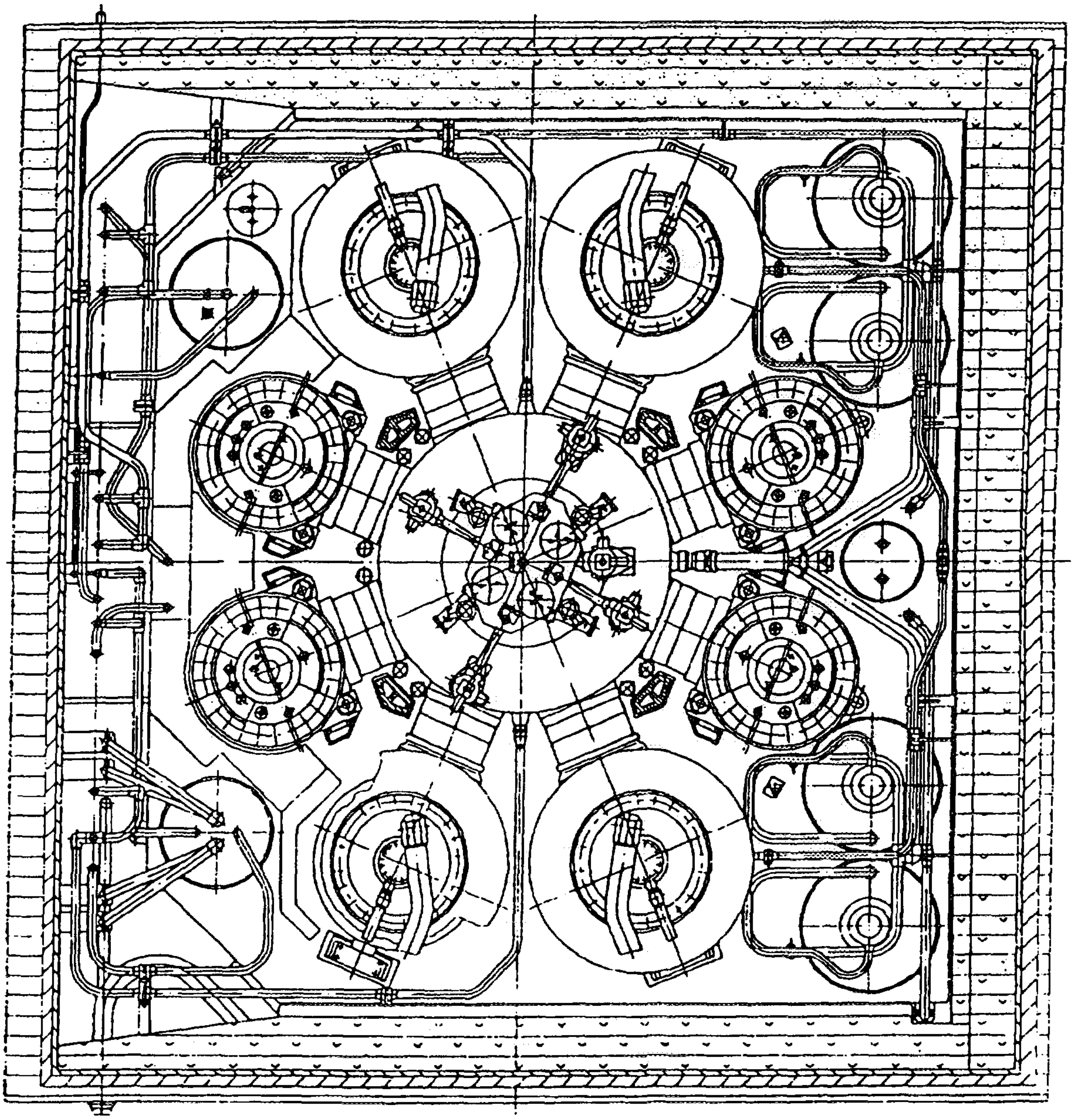


Fig. 1b. KLT-40 reactor plant.

- possibility of installation in different coastal regions of the world;
- high fabrication quality at a shipyard and "turn-key" delivery to the Customer in a short period of time.

For any of the options, the supply of electrical energy to users within the plant is provided by the shipboard electric power station.

2. CHOICE OF EQUIPMENT AND SCHEME FOR REACTOR AND DESALINATION PLANT COUPLING

Analysis of schemes for coupling of reactor with desalination plants is performed so as to achieve the specified thermal power of the reactor with maximum efficiency and minimum probability of radioactive contamination in the desalinated water. Therefore turbo-generators with condensing and back pressure turbines were considered for the electrical plant, and distillation or reverse osmosis plants for the desalination plant. Electricity generated was used for the station's own needs, for seawater desalination or for sale. Thermal power was supplied to distillation type desalination plants either by intermediate steam extraction from the turbine or by removal of heat from a back pressure turbine condenser.

It seems that the most preferable from the above mentioned point of view is a design using a condensing turbine with high cycle efficiency and a reverse osmosis desalination plant with low specific consumption of electric energy. It is evident that this scheme completely excludes radioactive contamination of desalinated water. However, at present reverse osmosis is hardly the most economic method due to limited lifetime of the filter elements, high costs for service and treatment of fresh water.

Desalination stations of the APWS-80 type using distillation plants with back pressure turbines are of practical interest. Heat for the distillation plant is supplied through an intermediate circuit, with water pressure exceeding the pressure in the adjacent circuit from the reactor side in order to prevent ingress of radioactive contamination in the event of heat exchanger leakage.

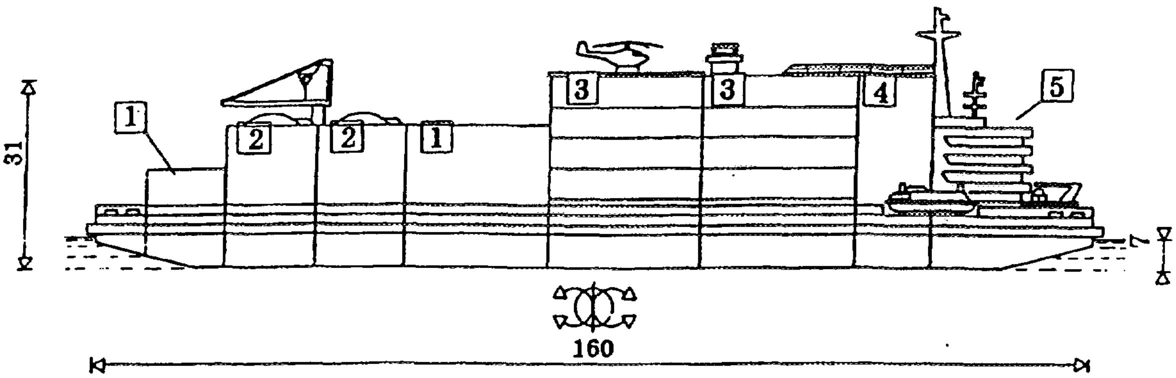
3. APWS-80 FLOATING NUCLEAR POWER STATION FOR PRODUCTION OF ELECTRICITY AND SEAWATER DESALINATION BY DISTILLATION

The APWS-80 floating nuclear seawater desalination plant is a special non-self-propelled ship with two-reactor power plants designed for production of electricity and seawater desalination. It is intended for use in a protected water area, together with a complex of external servicing structures. The main ship layout and the principle flow diagram of the station are shown in Figs 2 and 3. The station's main technical data are as follows:

Station Main Technical Data

Width, m	160
Breadth, m	44
Draught, m	7
Desalinated water capacity, m^3/d	80 000
Electric power (gross), MW(e)	~25
Electric power consumed by station, MW(e)	~ 10

The reactor operates at a reduced power of approximately 80 MW(th). If each reactor were to be operated at its full power of 160 MW(th), desalinated water capacity and electric power generation would be doubled.



1 - engine compartment

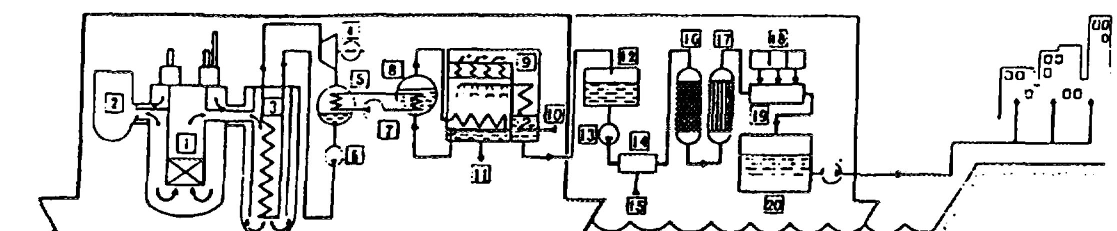
2 - central power compartment

3 - desalination plant

4 - potable water preparating plant

5 - living compartment

Fig. 2. Ship layout.



1 - reactor
2 - primary circuit circulator
3 - steam generator
4 - turbo-generator
5 - condenser
6 - secondary circuit electric pump
7 - intermediate circuit electric pump
8 - steam generator
9 - distillation desalinaton plant
10 - sea water
11 - evaporated sea water
12 - intake tank for distillation
13 - electric pump of potable water preparation plant
14 - mixer
15 - H_2CO_3 solution
16 - water enrichment facility
17 - running water ssorbent containing filter
18 - plant for fluorine, chlorine water treatment and stabilization
19 - mixer
20 - potable water tank

Fig. 3. Principal flow diagram of the station.

Besides the reactor plant, the station includes the desalination plant, a drinkable water production plant, and ship general systems. As the desalination plant, four distillation plants with film-type horizontal-tube evaporators are used in APWS-80. Many years of experience exist using analogous plants for an industrial complex in Aktau (Kazakhstan).

Excess electricity can be used either for the production of additional desalinated water using reverse osmosis or for sale. The cost of desalinated water can be materially reduced by compensating part of the production costs out of the profits from sale of electric energy.

Construction of desalination plants using distillation plants with film-type horizontal evaporators seems to be the most practical at this time. The use of back pressure turbines as the source of thermal energy results in some excess electric energy in relation to the power consumed for the station's own needs.

In order to reduce the probability of radioactive contamination of the desalinated water, two intermediate circuits are provided in the station design. One of these is pressurized to a higher pressure than the reactor side circuit.

4. NUCLEAR FLOATING COMPLEX (STATION) FOR PRODUCTION OF ELECTRICITY AND FOR WATER DESALINATION USING REVERSE OSMOSIS

As previously stated, the most economical approach is seawater desalination using reverse osmosis. Therefore, in parallel with the APWS-80 development, a floating complex for the production of electricity and seawater desalination using reverse osmosis was developed. It is proposed that this system use high thermal efficiency condensing turbines in conjunction with the desalination units.

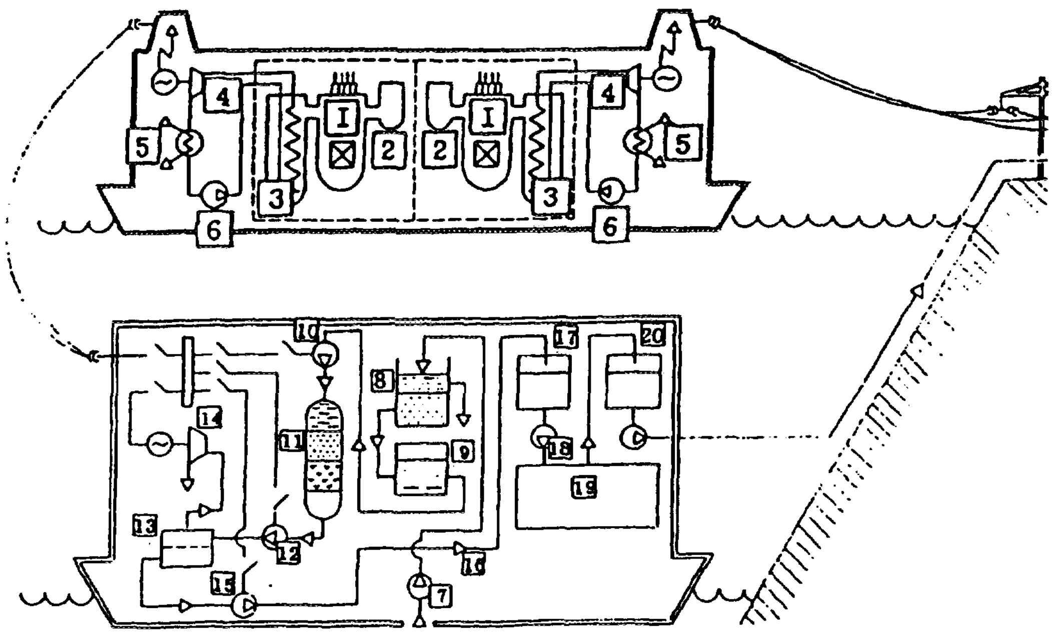
The complex includes two floating structures: a floating nuclear power station (FNPS) and a ship for seawater desalination using reverse osmosis (Figs 4 and 5). The floating nuclear power station is a special non-self-propelled ship for the production of electricity. It is designed for use in a protected aquatorium, or harbour. The station includes:

- Two nuclear steam supply systems of the KLT-40 type;
- A steam turbine plant;
- An electrical generating plant;
- Servicing facilities and ship's general systems.

Main FNPS Technical Data

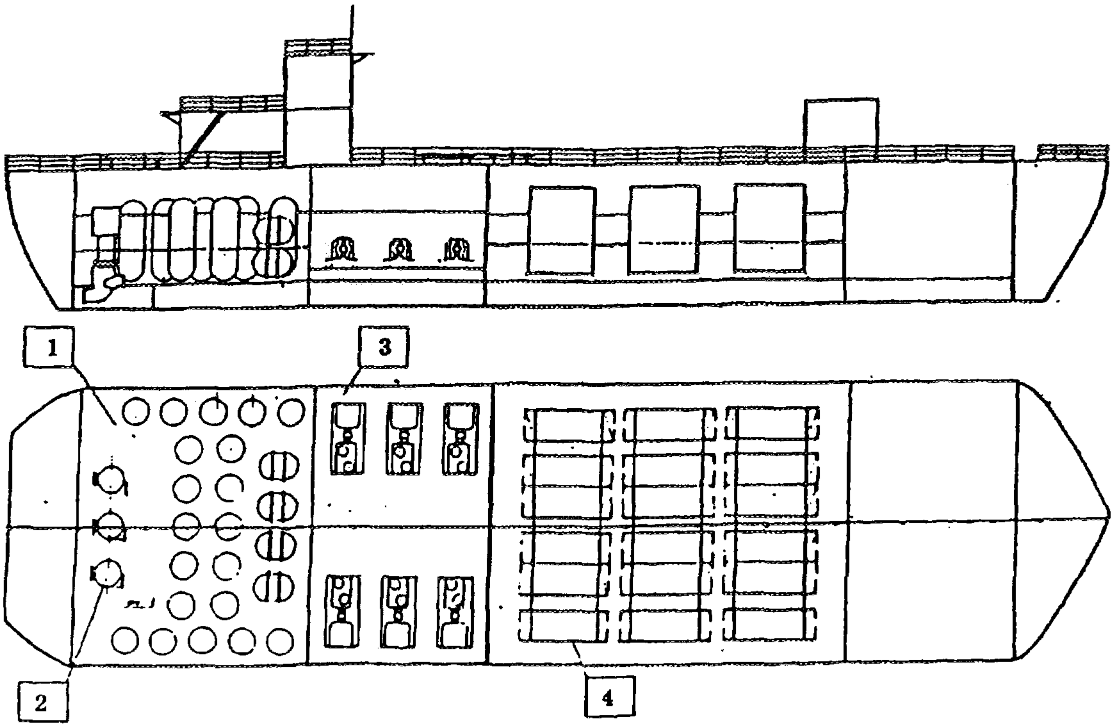
Length, m	120
Width, m	28
Draught, m	3.5 - 4 5
Electric power (gross), MW	~ 70
Electric power consumed by FNPS, MW	~ 5
Reactor power, MW(th)	160

The rapid maneuvering characteristics of the ship's reactor plant allow it to closely follow power demand, and thereby to ensure highly economical operation.



1 - reactor
2 - primary circuit circulating pump
3 - steam generator
4 - turbogenerator
5 - condenser
6 - secondary circuit electric pump
7 - sea water
8 - gravity filter
9 - clarified water tank
10 - booster pump
11 - twin-layer pressure filter
12 - high pressure filter
13 - reverse osmosis module
14 - hydroturbine
15 - fresh water pump
16 - filtrate
17 - filtrate intake tank
18 - electric pump of potable water preparation system
19 - potable water preparation unit
20 - potable water storage tank

Fig. 4. Principal flow diagram of the complex.



1 - room for sea water pre-treatment system

2 - booster pump

3 - desalinating system pump room

4 - desalinating modules

Fig. 5. Desalination plant layout.

The design and industrial enterprises of Russia are working on the development of a floating nuclear cogeneration plan for the country's northern regions. This can serve as a prototype for the FNPS desalination complex.

The electric energy generated by the FNPS is partially transmitted to the ship for seawater desalination and its excess is used for supply to coastal users.

This arrangement, which separates power generation and desalinated water production, has certain advantages over an arrangement in which they are combined on one floating structure. It simplifies a solution to the problem of preserving a high efficiency of desalinated water production from the complex when the reactors are shutdown by supplying the desalination plant with electric energy from the external grid. The scheme seems to be sufficiently flexible since it allows the optimal ratio for production of the required amounts of water and electric energy.

The ship for reverse osmosis desalination is a non-self-propelled structure housing systems and equipment providing for the supply of seawater, its pretreatment, desalination, supply of desalinated water to users, and cleaning of the desalination units (Fig. 5). With the objective of optimizing the of technical and economic characteristics of the complex, some variations with different desalinated water output were considered.

Desalinated water capacity, thousand m^3/day	0	20	40	80	318
Electric power required for desalination plant, MW (at specific consumption 4.9 kW·h/m^3)	0	4.1	8.2	16.4	65
Excess electric power of complex, MW	65	60.9	56.8	48.6	0

The desalinated water production plant can also be arranged on shore in the vicinity of the FNPS. The advantage of having the desalination plant arrangement on a ship is that there is the possibility of plant manufacture and testing at a shipyard in the Supplier country.

At present new technologies are being developed for seawater desalination using reverse osmosis. For example, in the Canadian CANDESAL desalination program the use of reverse osmosis technology is accompanied by preheating of the seawater in the turbine condenser. Preheating allows considerable reduction in the specific power consumption for desalination and in the cost of desalinated water.

In this connection it seems beneficial to develop a joint Canada-Russian project for floating nuclear power/desalination complex, with the FNPS based on the KLT-40 shipboard reactor plant and the new application of reverse osmosis seawater desalination.

5. CONSTRUCTION SCHEDULE

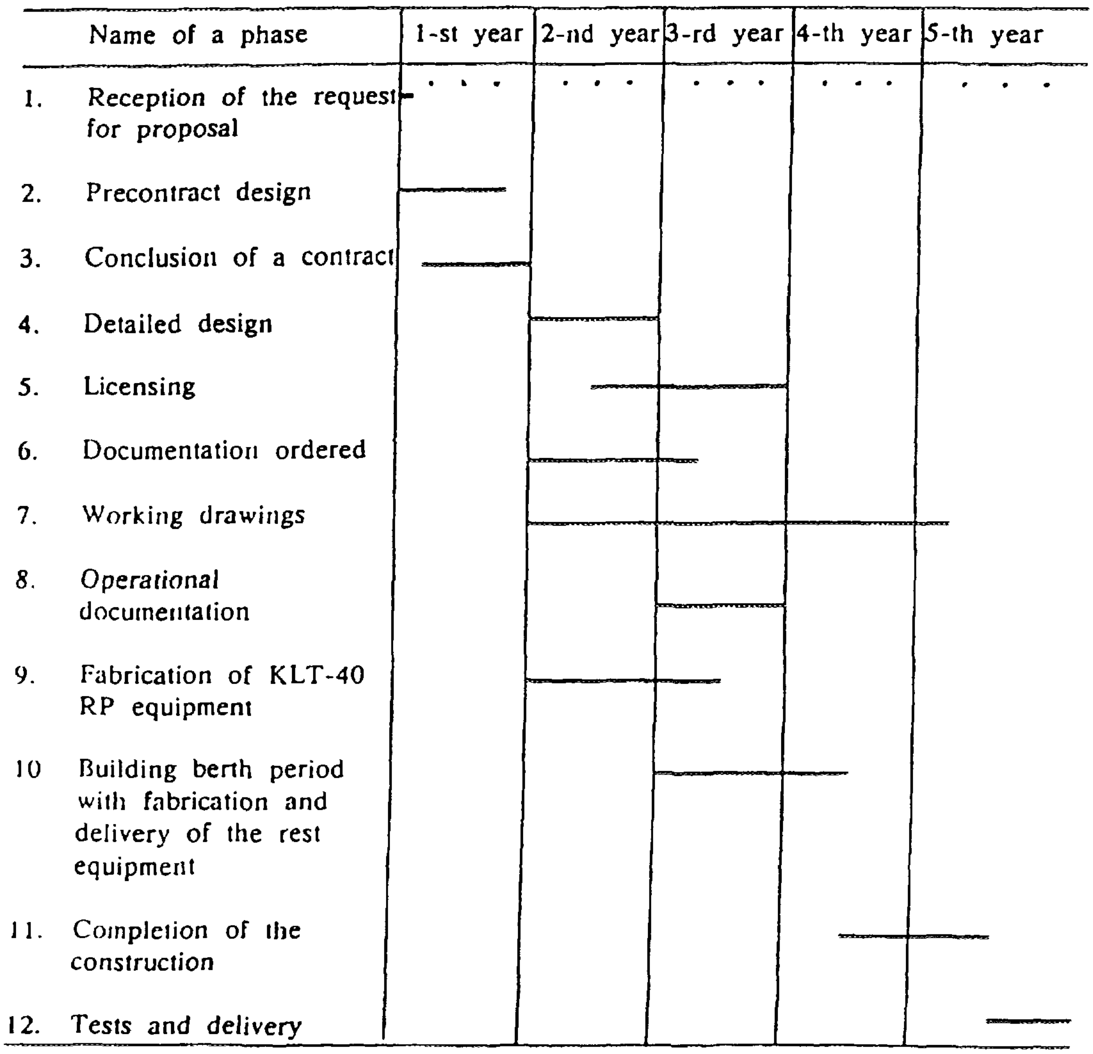
Approximately 300 million US dollars is required for construction of the prototype APWS-80 nuclear floating desalination station. The sum indicated may be returned to the countries financing the station creation after selling of the desalinated water and electricity produced. Specialists of these countries may have an opportunity to train at the prototype station.

A staged approach to the construction and operation of the prototype APWS-80 floating desalination station is envisaged, including:

- Search for a Customer;
- Development (in conformity with requirements of the Customer), construction and "turnkey" commissioning of the plant (4-5 years);
- Surveying the site and construction of external servicing structures around the mooring site (2-3 years);
- Shipping the facility to the mooring site (0.5 year);
- Its operation and maintenance;
- Facility decommissioning after the end of its service life.

Activity on design and construction of the station can begin immediately after contract signing.

Construction Schedule For APVS-80 Prototype Floating Station



6. CONCLUSION

As to level of safety and environmental impact, the floating nuclear desalination plant meets modern international codes and requirements, and can be recommended as a power/water desalination complex for the countries of North Africa, the Near East, and some regions of the Indian Ocean.

The principal engineering features of the station and its subsystems have been proven during many year of operation for both the reactor and desalination parts of the station. This allows a minim period of construction (4-5 years) and acceptable cost of desalinated water.

A floating nuclear cogeneration plant constructed in Russia can become a prototype power source for floating desalination complexes elsewhere. It can validate their viability, expedite their design/development and reduce their construction time.

It seems that participation of other country's designers and potential Customers in the development of floating nuclear desalination stations of the APWS-80 type is worthwhile.