XA9848809

TECHNICAL AND ECONOMIC EVALUATION OF NUCLEAR SEAWATER DESALINATION SYSTEMS

A.G. GRECHKO, A.A. ROMENKOV, V.A. SHISHKIN
Research and Development Institute of Power Engineering (RDIPE),
Moscow, Russian Federation

Abstract

The IAEA COGENERATION/DESALINATION COST MODEL spreadsheets were used for the economic evaluation of sea water desalination plants coupled with small and medium size nuclear reactors developed in RDIPE. The results of calculations have shown that the cost of potable water is equal to or even below 1$/m^3. This is very close to similar indices of the best fossil driven desalination plants. For remote and difficult-to-access regions, where the transportation share contributes significantly to the product water cost at fossil plants, the nuclear power sources of these reactor types are cost-efficient and can successfully compete with fossil power sources.

1. INTRODUCTION

For a number of years RDIPE has been developing nuclear power plant projects of a small and medium size, such as RUTA-TE [1], UNITHERM [2,3] and NIKA [4]. The said NPPs are intended to solve power supply problems for small settlements located mostly in remote and difficult-to-access regions where the transportation share contributes significantly to the fossil fuel cost. Nuclear power sources of this type are, in this case, cost-efficient and can successfully compete with fossil power sources.

Small and medium size NPPs can be successfully used for solving the problem of fresh water supply by means of sea water desalination. The given work presents feasibility study results aimed at finding an optimum combination of a nuclear power source and desalination plant and also defining the conditions for reasonable, in terms of cost-efficiency, implementation of nuclear sea water desalination projects with application of nuclear power sources developed by RDIPE.

2. SPECIFICATIONS OF NUCLEAR POWER SOURCES

2.1. RUTA-TE reactor plant

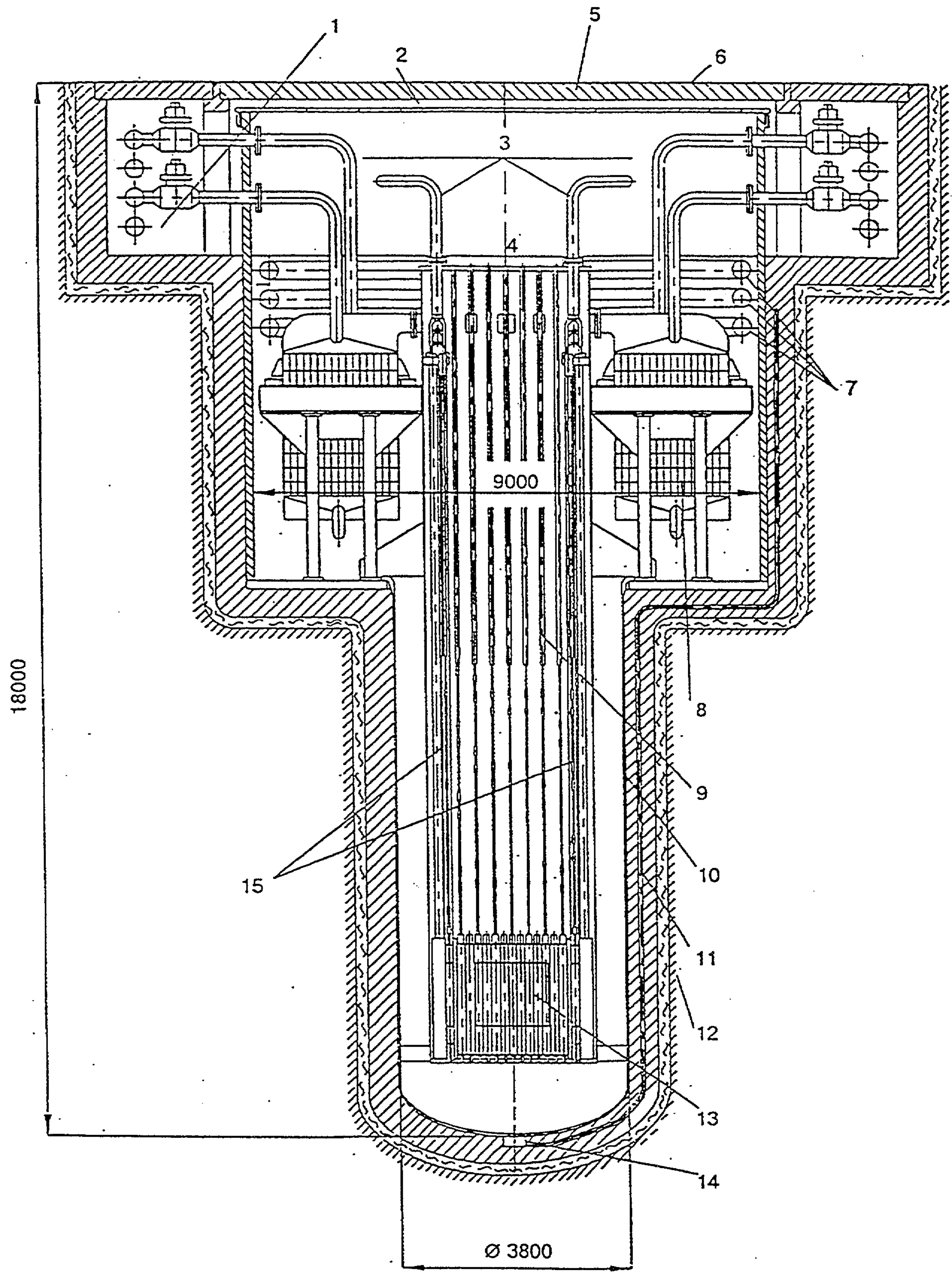
The RUTA-TE reactor is a pool-type thermal reactor whose distinctive features are a high level of safety and reliability being characteristic for pool-type reactors, a relatively low cost of manufacturing and capability to produce some amount of electric power alongside with heat generation. Key specifications of the reactor are given in Table I. Fig. 1 presents the reactor schematic diagram.

2.2. NIKA-type reactors

The NIKA-type reactors under development are integrated PWRs of new generation notable for higher reliability and safety. There are two options for their use: for ground-based and floating NPPs. Table II presents their characteristics. The NIKA-120M NSSS design for a floating NPP is shown in Fig. 3.

2.3. UNITHERM transportable NPP

The UNITHERM reactor represents a small-size PWR whose distinctive features are transportability (delivery to the site as the ready-made blocks), a unique service life (20 years) with a single nuclear fuel loading for remote difficult-to-access places without use of local cooling water



1 - headers and valves compartment, 2 - reactor lid, 3 - feed/steam piping, 4 - water level, 5 - protective plate, 6 - ground surface level, 7 - pressurizers, 8 - primary heat exchanger, 9 - control rod drive, 10 - pool lining, 11 - concrete, 12 - ground, 13 - core, 14 - leakage monitoring device, 15 - modular channels

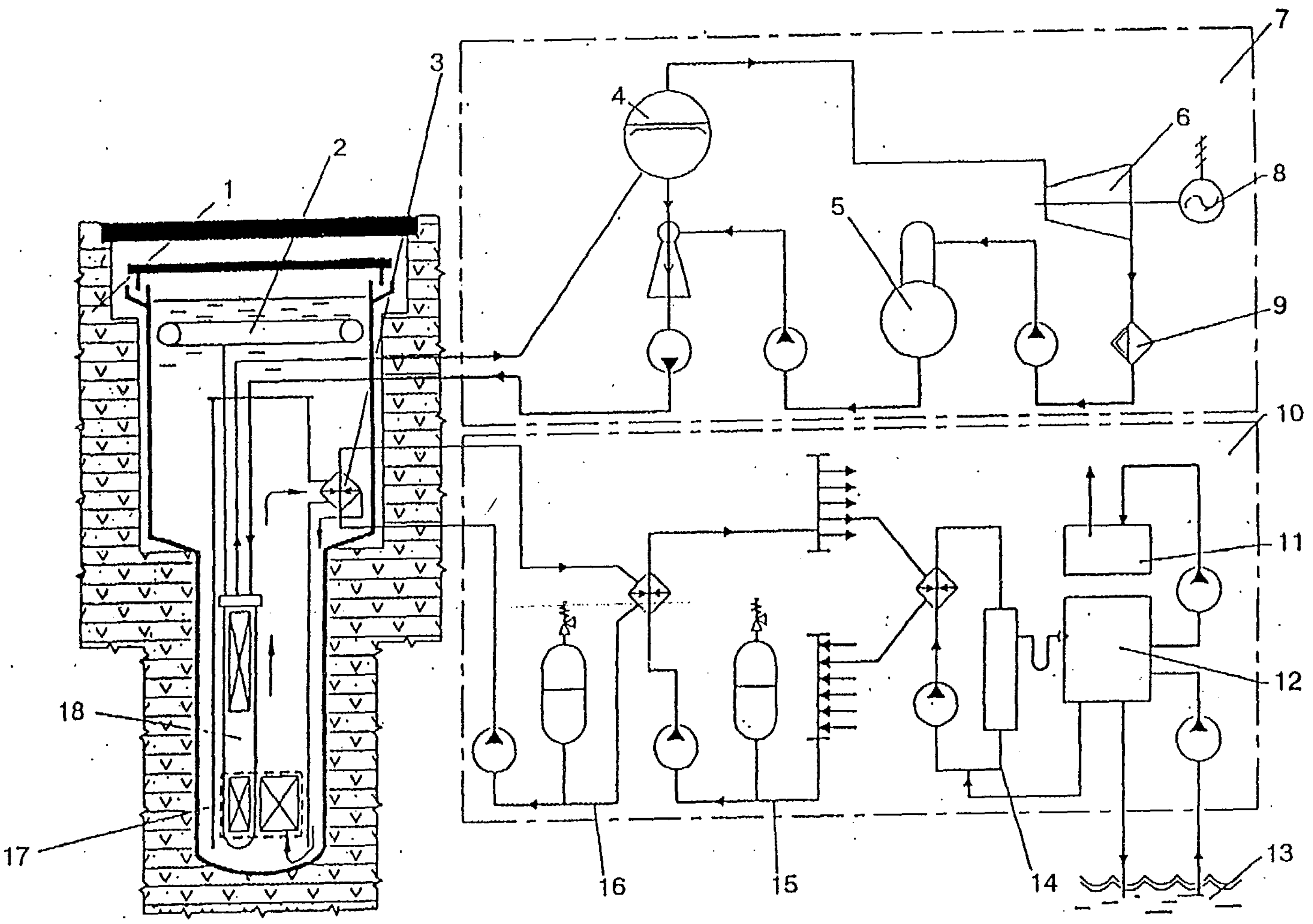
Fig. 1. Reactor RUTA-TE.

Table I Main characteristics of RUTA-TE

Parameter	Value
Total core thermal power, MW(t)	70,4
Net reactor heating capacity, MW(t)	65,5
Net reactor electrical power, MW(e)	3,5
Steam generating capacity, kg/s	6,5
Superheated steam pressure, MPa	3,0
Superheated steam temperature, ^{0} C	263
Feed water temperature, ^{0} C	160
Pool water parameters: ■ inlet/outlet temperature, ^{0} C ■ pressure at the core level, MPa ■ water volume in the pool, m^3	 74/101 0,228 600
Modular channel water parameters(max.): ■ inlet/outlet temperature, ^{0} C ■ pressure at the core level, MPa ■ water volume in the channel, m^3	 274/306 9,8 0,07
Average thermal capacity of the modular channel, MW(t)	192,3
Number of modular channels	78
Number of fuel assemblies in the central part of the core	169
Turbine efficiency, %	26,7
Temperature of reactor plant direct hot water, ^{0} C	85
Temperature of reactor plant return water, ^{0} C	60

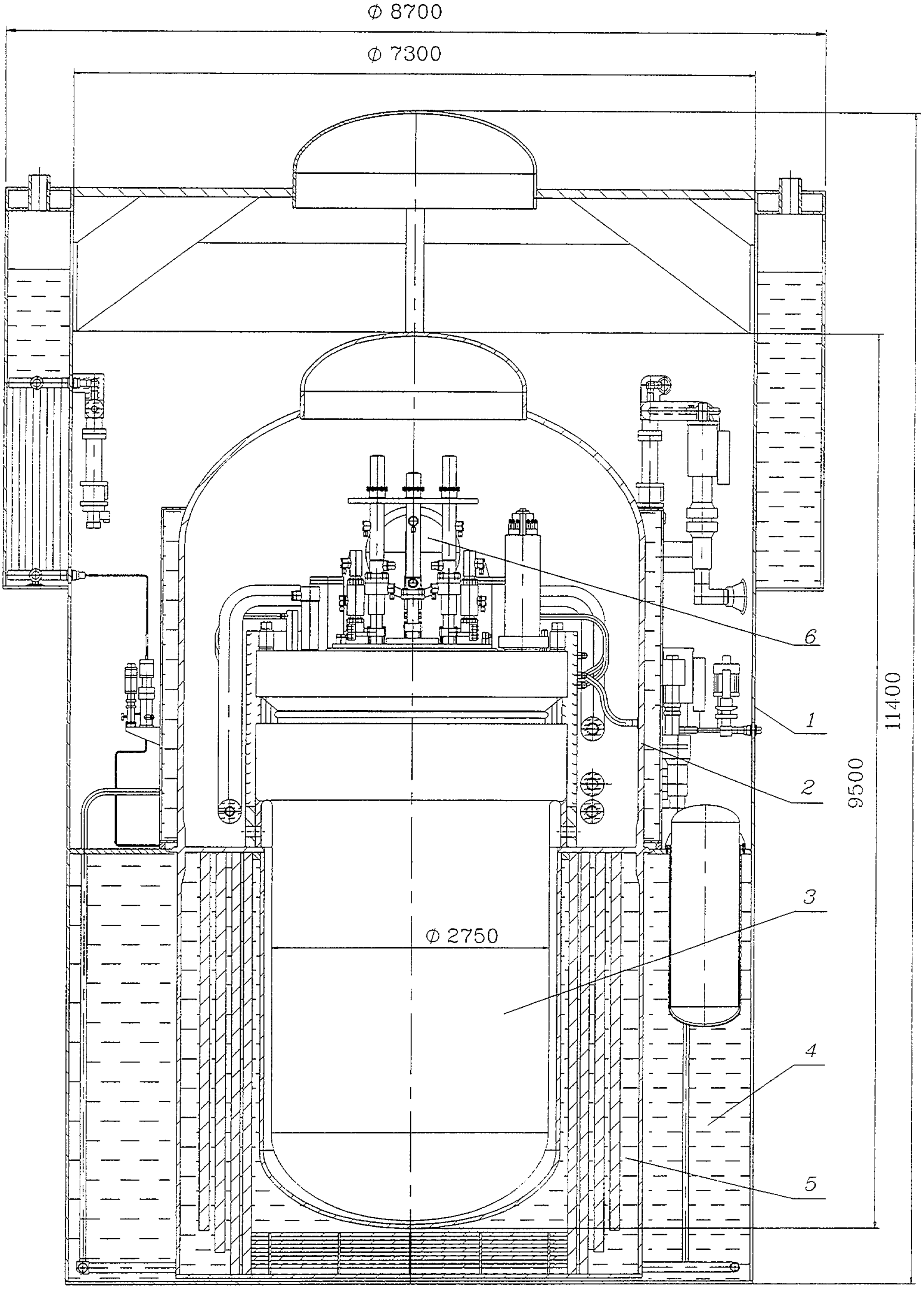
Table II Design characteristics of NSSS of NIKA type and of UNITERM.

No.	Characteristic	NIKA-120M	NIKA-300	UNI-TERM
1	Thermal power of the core, MW(t)	70	300	15.3
2	Steam generating capacity, kg/s	25	138.8	5.6
3	Superheated steam pressure, MPa	3.0	3.0	1.2
4	Superheated steam temperature, at least, °Ñ	274	274	210
5	Feed water temperature, °Ñ	60	180	45
6	Nominal pressure in primary circuit	15	15	16
7	Primary coolant temperature while operating at nominal power, °Ñ: at core inlet at core outlet	 260 300	 270 310	 245 325
8	Operating range of power change, % $N_{nom.}$	20...100	20...100	25...100
9	Effective campaign of core, years	4	4	20
10	Fuel: U^{235} enrichment, % U^{235} load, kg specific power rating, kW/l	 19.7 251 40	 5 637 65	 21 160 15
11	Service life, years	30	60	40



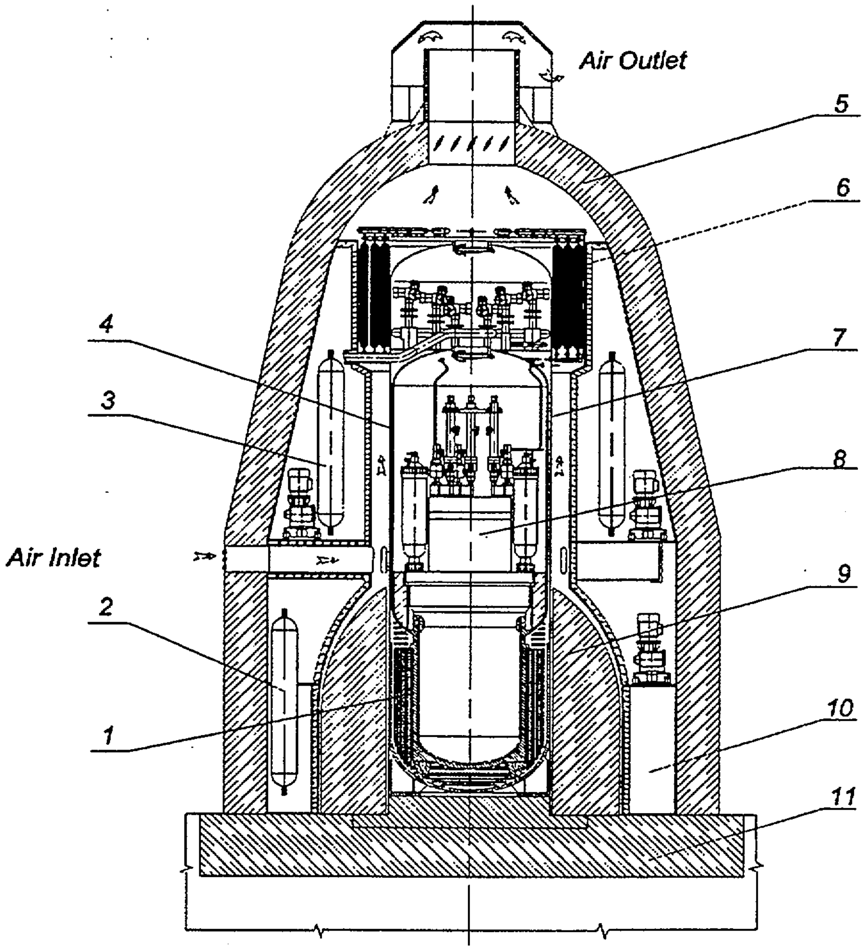
1 - reactor island, 2 - pressurizer, 3 - primary heat exchanger, 4 - separator, 5 - deaerator, 6 - turbine, 7 - turbine island, 8 - generator, 9 - condenser, 10 - desalinating island, 11 - fresh water storage, 12 - water distillation plant, 13 - sea, 14 - vaporization circuit, 15 - third circuit, 16 - secondary circuit, 17 - core, 18 - modular channel

Fig. 2. Co-generating plant flow diagram.



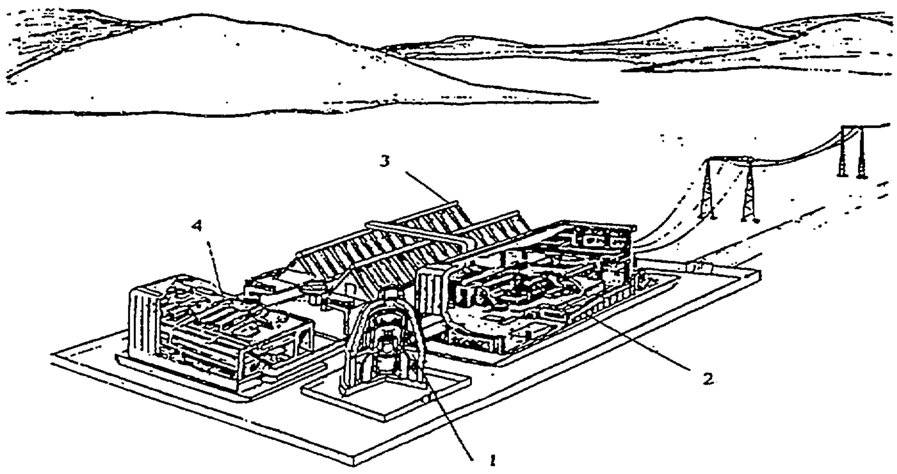
1 Containment
2 Safeguard vessel
3 Reactor
4 External tank
5 Internal tank
6 Entrance hatch

Fig. 3. Longitudinal section.



1 - iron-water shielding tank; 2 - radioactive gases storage cylinders; 3 - liquid absorber supply system; 4 - containment; 5 - shock-proof casing; 6 - cooldown system heat exchanger; 7 - safeguard housing; 8 - steam generating unit; 9 - biological shielding blocks; 10 - liquid and solid wastes storage tanks; 11 - basement

Fig. 4. Reactor plant.



1 - reactor plant; 2 - turbine; 3 - air cooler condenser; 4 - main control room

Fig. 5. UNITHERM NPP.

sources, the principle of "green grass" on completion of functioning, and high-level safety. The characteristics are given in Table II. The UNITHERM NSSS design is presented in Fig. 4 and the UNITHERM NPP design is shown in Fig. 5.

3. CALCULATION TECHNIQUE AND INPUT DATA

The economic evaluation of sea water desalination for complexes using nuclear reactors developed by RDIPE were performed by the IAEA COGENERATION/DESALINATION COST MODEL spreadsheets[5]. Basic input data are given in Table III. Some features of calculations are as follows.

An optimum maximum brine temperature at which the cost of fresh water becomes lowest was determined first while calculations for multi-effect distillation (MED) and hybrid water plants were run. The remaining input data for desalination plants were taken from the default values in the spreadsheet programme.

Calculations for fossil driven desalination plants were also performed to compare them with performances of nuclear driven desalination plants. For this, the cost of fossil fuel was assumed to be 15.5 $/BOE.

The given spreadsheets were modified to calculate the RUTA-TE nuclear plant, since they did not envisage a power plant model with an independent heat and power output. The modification consisted in reducing to zero the work lost on turbine shaft due to failure of steam to expand up to the condensation temperature of 37 °C because such losses are not available here.

The UNITHERM NPP secondary circuit consists of two loops. The first loop serves to drive an electric generator of the turbine. The second loop serves for supplying heat as steam or hot water. Since the IAEA spreadsheets do not envisage such a reactor arrangement, it was assumed for the calculations that the whole energy is removed via the first loop to the turbine but the second loop is not actuated. The UNITHERM NPP is expedient for delivery in a two-unit version. The calculations were just performed for this version.

Table III Input data for calculations

Input data	NIKA-120M (2 units)	NIKA-300	RUTA-TE (2 units)	RUTA-TE (4 units)	UNI-TERM (2 units)
Thermal power of the core, MWt	2*70	300	2*70.4	4*70.4	2*15
Net electrical power, MWe	2*15	90	2*3.5	4*3.5	2*2.07
Specific cost of construction , $/kWe	3500	2100	7300	6800	9000
Specific O&M cost, $/MWeh	6.0	5.0	9.0	9.0	15.0
Specific nuclear fuel cost, $/MWeh	25	17	27	27	21
Operating availability	0.8	0.9	0.95	0.95	0.9
Power plant economic life, a	30	30	60	60	40
Interest rate, %	8	8	8	8	8

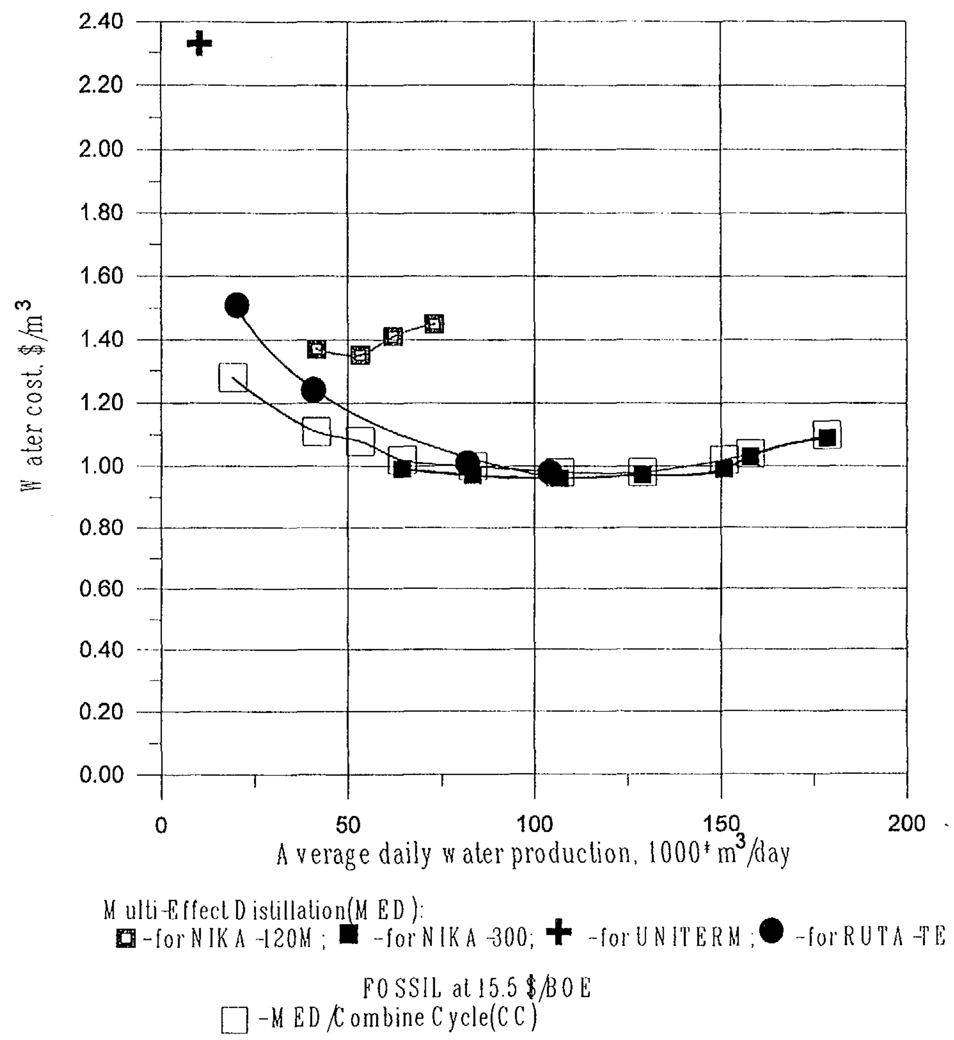


Fig.6a. W ater cost versus w ater production for multy-effect distillation(M ED) plants.

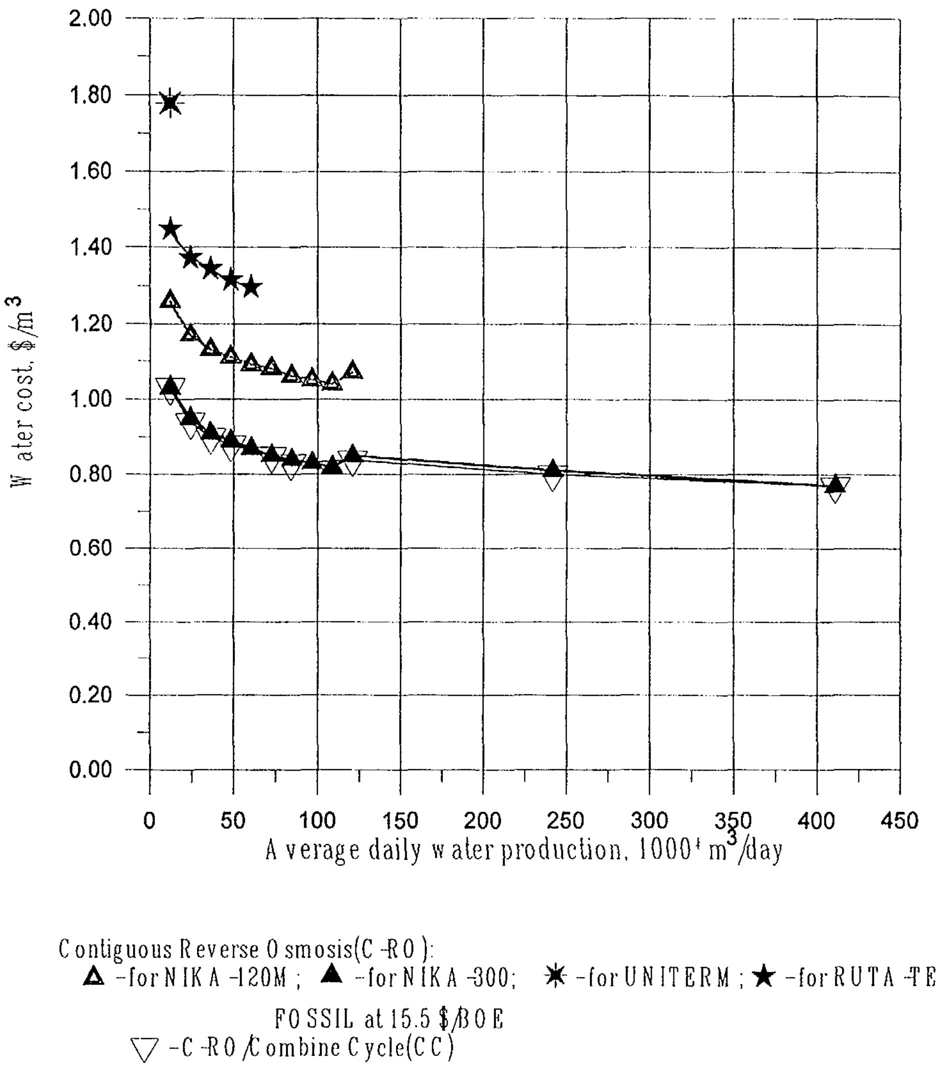


Fig.6b. W ater cost versus w ater production for contiguous reverse osmosis(C -RO) water plants.

Table IV Results of calculations

Characteristic	NIKA-120M (2 units)	NIKA-300	RUTA-TE (2 units)	RUTA-TE (4 units)	UNI-TERM (2 units)
Levelized power cost, $/kWeh	0.088	0.050	0.151	0.143	0.178
*Average daily fresh water production, 1000*m³/day*					
Multi-Effect Distillation(MED)	41.6...73.1	64.4...179	40.8	104.1	10.4
Contiguous Reverse Osmosis (CRO)	12.1...121	12.1...411	12.1...24.2	12.1...60.4	12
Hybrid (MED + RO)	60...120	72...409	-	-	-
Fresh water cost, $/m³					
MED	1.37...1.45	0.98...1.04	1.24	0.98	2.33
CRO	1.26...1.04	1.03...0.77	1.58...1.50	1.45...1.29	1.78
MED+RO	1.35...1.19	1.00...0.89	-	-	-
Total investment cost, M$					
Power Plant	132	252	63	118	45
MED	108...183	154...422	84	233	31
CRO	17...158	17...443	17...34	17...79	17
MED+RO	125...200	154...525	-	-	-

4. CALCULATION RESULTS

Table IV and Fig. 6a,b present some calculation results.

For the RUTA-TE reactor, the cost of water desalinated in the reverse osmosis (RO) plants is higher than the cost of the water produced in RO plants with fossil fuel by about 40 %. This is explained by high specific cost of electricity produced by this reactor. The RUTA-TE reactor is expedient for the application together with the distillation desalination plants. In this case the cost of water is lowest, approximately 1 $/m^3, which is very close to similar indices of fossil fuel plants. In addition, it should be also kept in mind that the quality of distilled water is higher than the quality of water obtained from RO plants (salinity is 25 ppm for MED plants and 300 ppm for RO plants).

For the NIKA-120M reactor the fresh water cost is above those for fossil fuel plants by about 20 to 40 %. But an advantage such as transportability of the reactor by sea (floating design version) may play a major role for choosinga reactor plant for the seawater desalination.

For the NIKA-300 reactor the fresh water cost is very close to the one for the best fossil plants. A power plant based on this reactor can operate in combination with a desalination plant of any type and produce fresh water at a very low cost.

For the UNITHERM NPP the fresh water cost exceeds similar indices for fossil plants. For distillation plants the difference reaches up to 60 % and for RO plants - up to 80 %. However, low capacity desalination plants in combination with the UNITHERM NPP may turn to be cost-efficient in remote difficult-to-access regions.

5. CONCLUSIONS

Desalination plants with the nuclear power plants under consideration have no decisive advantage so far over fossil driven desalination plants in term of desalinated water costs. However, they have merits, such as a substantially longer duration of operation with a single fuel loading and the freedom from environment contamination by the fossil fuel combustion products. Nuclear desalination plants are presently expedient to be applied in remote, difficult-to-access regions whereto the supply of fossil fuel is difficult and expensive, for instance, in Extreme North remote areas and difficult-to-access desert regions. In future, nuclear desalination plants may probably become more cost-efficient than fossil desalination plants as the reserves of fossil fuel decrease and the related fossil fuel becomes expensive.

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