DEVELOPMENT OF SMALL (10 MW THERMAL) NUCLEAR PLANT WITH LEAD–BISMUTH COOLANT FOR ELECTRICITY AND HEAT CO-GENERATION, PRODUCTION OF FRESH WATER AND HYDROGEN

O.I. KOMKOVA, G.J. KONONENKO, P.V. PUCHKOV, V.I. SIDOROV, M.M. TREVGODA
Institute of Physics and Power Engineering (IPPE),
Obninsk

XA9848815

S.Z. VERHOVODKO
St. Petersburg Marine Building Bureau,
St. Petersburg

Russian Federation

Abstract

The paper is presented to evaluate the possibilities of developing a small capacity transportable nuclear power and technology plant (SC TNPTP) with lead-bismuth as a coolant intended for electricity and heat supply, production of fresh water and hydrogen. Its basic distinctive features compared to other various small capacity nuclear power plants (SC NPPs) under development are: simplified design; extended life time; safety and reliability; a pumpless scheme of coolant circulation; utilization of a gas turbine facility with a closed circuit; variable production ratios of the electricity, heat and its products such as fresh water and hydrogen. All these features give grounds for a new generation nuclear power and technology plant (NPTP). TNPTP uses a compact desalinator based on a multi-effect distillation process and/or an electrolizer with metal hydrides for hydrogen accumulation. The plant's capacity of 10 MW(thermal) has been chosen based on the economic optimization of the electricity and thermal heat to be supplied for the production of fresh water and hydrogen (even if the operations are simultaneous, i.e., cogenerating) in the isolated regions far remote from the centralized energy supply sources.

The main purpose of the research

The general purpose of the research was to identify main characteristics of small capacity NPPs (SC NPPs) (10MW thermal), for electricity production and thermal energy supply for heating, desalination of sea water and for hydrogen production. The NPP to be pursued should have superior characteristics compared with other SC NPPs known, in terms of safety, life time, deliverability of the equipment to the construction site with maximum readiness for service, the possibility to produce various products, and to change the ratio between the energy types to be generated depending on the amount of electricity and heat, fresh water or hydrogen demands. In the research the experience of NPPs for ships has been extensively used.

Research substantiation

Under growing shortage and increasing costs of electrical and thermal power supplied from the centralized nets, there are various incentives to develop universal, reliable, safe and economic autonomous sources of electricity and thermal energy to be used for heating, water desalination and hydrogen generation. They are: increasing costs of organic fuels in Russian Federation; increasing number of economic communities independent in their power supply; and the importance of producing effective energy carrier like hydrogen.

The lead-bismuth properties such as no burning, no interactions with water, high boiling temperatures offer a good opportunity of developing a SC lead-bismuth NPP with improved characteristics of safety and economy as compared with SC NPP of other types. A disadvantage of an prototype SC NPP with Pb-Bi named TES-M is that its power is comparatively small (1 MWe per unit). It is necessary to increase its power (at least twice), with no considerable increase of its mass and

dimensions, and without impairing favourable other characteristics. This should be the main goal of the project. Research works carried out by specialized institutions (e.g., RPA "Malaya Energetica" - Small Scale Power Engineering - Moscow) made it possible to determine the economically competitive minimum capacity of NPP. It is about 3-4 MWe for the Russian conditions.

The main NPP technical specifications

- A core with thermal (or intermediate) neutron spectrum.
- Application of liquid metal Pb-Bi as a coolant.
- Low core power density.
- Integrated configuration of the primary circuit in one pressure vessel. Thus the circulation contour of the primary coolant becomes simpler, and compact and simple design can be pursued.
- Equipment of the primary circuit (the core absorber rods and gauges, modular air heaters, devices of coolant technology) is of replaceable type.

One of conditions of improved reliability and extended life time of a reactor facility (RF) will be the ellimination of a mechanical pump for circulating the primary circuit coolant. The coolant is circulated by natural convection. The capacity of this facility may be increased up to 10 MWth using additional pumpless means of circulation, e.g., gas injection above the core to intensify the circulation (gas lift method). Furthermore TNPTP includes:

- carnotype gas turbine facility (GTF) with a closed circuit;
- desalinator based on the multi-effect distillation process;
- hydrogen producing and accumulating systems.

The plant can be fabricated in several transportable blocks or as a floating plant. The preliminary main characteristics of the facility proposed are listed in Table I.

Table I Main technical characteristics

No.	Parameter, measurement units	Value
1.	Unit's thermal power, MW	10
2.	Maximum electrical power, MW	2
3.	Maximum thermal power supplied, MW	8
4.	Maximum yield of fresh water, m^3/day	5000
5.	Air temperature at the inlet of the air heater, °C	255
6.	Air temperature at the air heater outlet, °C	500
7.	Outlet air pressure, MPa	0.35
8.	Temperature of coolant at the core inlet, °C	400
9.	Temperature of coolant at the core outlet, °C	520
10.	Core height, mm	~1000
11.	Core diameter, mm	~1000
12.	Integral reactor facility dimensions, D×H, mm	~2500×3000
13.	Weight of a mono-unit, t	~50
14.	Operation time; effective hours	90 000
15.	Uranium-235 load, kg	70
16.	Fuel material	U-Zr alloy
17.	Energy converter type	carnotype GTF with a closed circuit
18.	Fabrication type	Transportable blocs or floating type

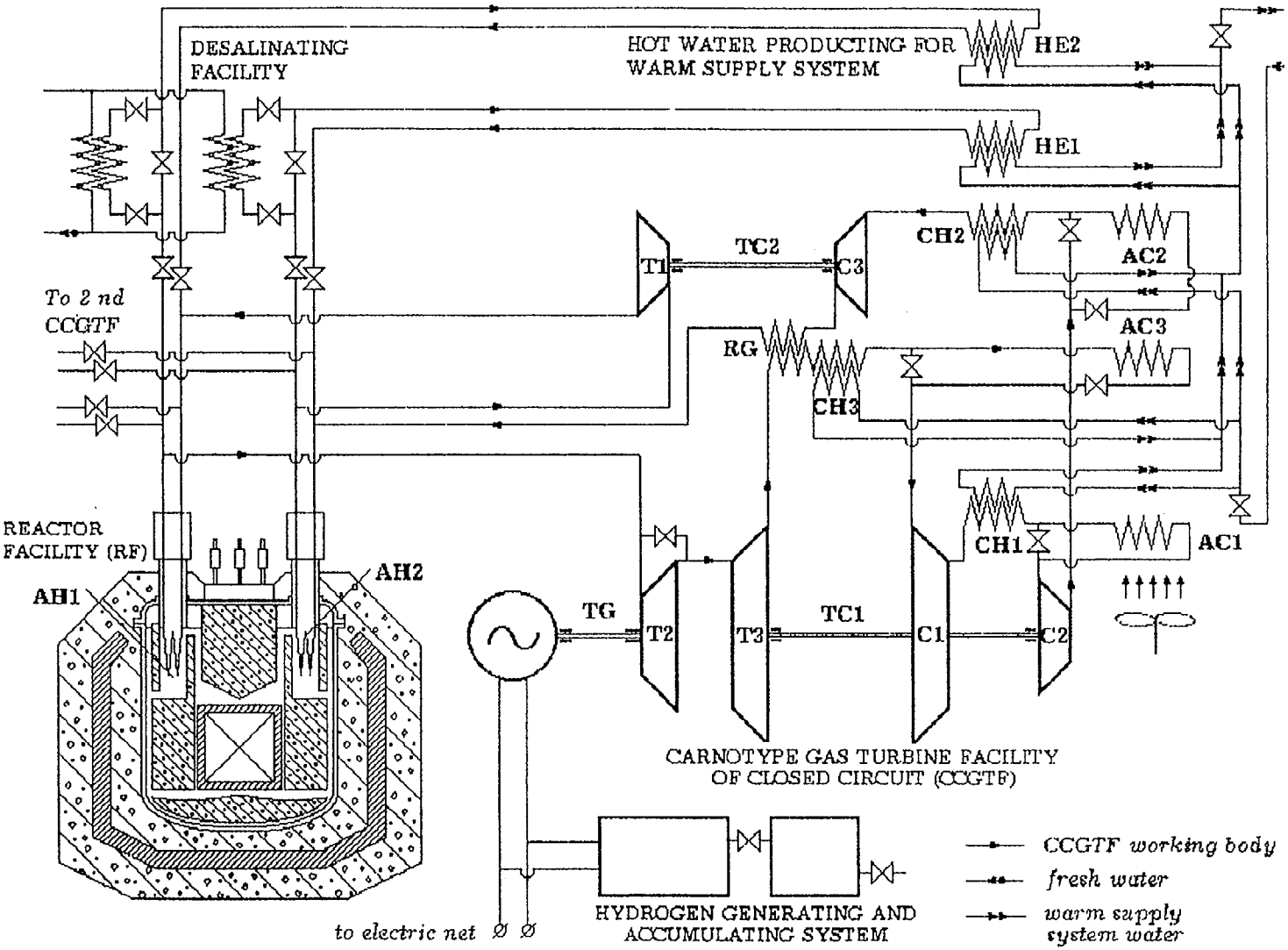

Fig. 1. TNPTP block principle scheme.

The state of the technology offered

Ample experience has been accumulated with all principal elements of the NPP: RF, energy converter, technological systems, desalinating devices and hydrogengeneration facility. Prototype NPPs are available, with pumped coolant circulation and steam turbine installations as energy converters.

The facility proposed differs from the existing ones: it has no mechanical pumps; more compact and safer GTF of a closed type is installed instead of a steam turbine; power density of the core is decreased. SSC RF IPPE and the Central Design Bureacx of Machine Building (CD BM, S.-Petersburg) have prepared a conceptual design of a similar NPP of 1 MWe on the order of Kamchatenergo (without desalinating and hydrogengenerating systems).

Additional means for pumpless circulation of the coolant is introduced in this SC NPP proposed. It provides a considerable increase (at least two-fold) of the prototype NPP power, which may result in a considerable expansion of possible development of the reactor. A characteristic feature of the new NPP is that the open cycle is replaced by a carnotype GTF with closed circuit (CC GTF) improving the plant's competitiveness and safety. Experience necessary for this application is already available from CC GTF, desalination and hydrogen production systems.

Potential advantages of the NPP proposed

The SC NPP proposed is intended for supplying power to isolated regions difficult to access, water desalination and hydrogen generation. It has the following potential advantages as compared to alternative power plants:

- maximum shop fabrication and minimum construction and mounting work at the construction site;
- transportability even in bad transportation conditions;
- comparatively simple design and improved reliability;
- increased safety in transportation, mounting works, operation and dismantling;
- comparatively low cost, due to a small fuel load and simple design;
- ecological compatibility;
- long life time (without reloading);
- minimum services required during operation;
- flexibility of the ratio of energy generated (electric/thermal) depending on required electricity and heat, the output of fresh water and hydrogen.