A MULTI-PURPOSE REACTOR

CHANGWEN MA
Institute of Nuclear Energy Technology,
Tsinghua University Beijing,
Beijing, China

Abstract

A integrated Natural circulation self pressurized reactor can be used for sea water desalination, electrogeneration, ship propulsion and district or process heating. The reactor can be used for ship propulsion because it has following advantages: It is a integrated reactor. Whole primary loop is included in a size limited pressure vessel. For a 200MW reactor the diameter of the pressure vessel is about 5m. It is convenient to arranged on a ship; Hydraulic driving facility of control rods is used on the reactor. It notably decreases the height of the reactor. For ship propulsion, smaller diameter and smaller height are important. Besides these, the operation reliability of the reactor is enough high, because there is no rotational machine (for example, circulating pump) in safety systems. Reactor systems are simple. There are no emergency water injection system and boron concentration regulating system. These features for ship propulsion reactor are valuable. Design of the reactor is on the base of existed demonstration district heating reactor design. The mechanic design principles are the same. But boiling is introduced in the reactor core. Several variants to use the reactor as a movable seawatwer desalination plant are presented in the paper. When the sea water desalination plant is working to produce fresh water, the reactor can supply electricity at the same time to the local electricity network. Some analyses for comprehensive application of the reactor have been done. Main features and parameters of the small (Thermopower 200MW) reactor are given in the paper.

1. A CONCEPT OF USING THE HEATING REACTOR FOR PROPULSION

Originally, the purpose of the heating reactor is to supply heat for Buildings in cities. Now we want to extended its application to propulsion, heat-electro-cogeneration, sea water desalination and refrigeration (for air condition) etc.

In the regions, where fresh water resources are deficient, transport of fresh water is need. Usually ship transport is used. This way to transport water is not convenient. If a reactor is mounted on a ship, as a desalination power source, at the same time as a propulsion power resource, that would be a interesting solution.

For example, in China for several islands fresh water is need. A movable desalination plant is a feasible solution. When the plant arrived the island, it can supply some additional electro- power to the local network. This isn't negligible in China.

Heat and power cogeneration (for sea water desalination and propulsion) will improve the economic features of the reactor.

(1). Multi- purpose ,extends applications of the Heating Reactor.

(2). As a power source, the reactor can work whole year, From view point of economy, it much better than only supply heat for buildings in cities.

2. HEATING REACTOR IS APPROPRIATE AS A PROPULSION POWER RESOURCE

As a propulsion power source Heating Reactor has following advantages:

(1) Sizes are limited. Heating Reactor adopted integrated arrangement. Whole primary loop is included in a pressure vessel. Sizes of the pressure vessel are limited. A compact arrangement for the ship propulsion power source is a important factor.

(2) Height is less. Hydraulic driving facility is used in the Heating Reactor. It makes the Height of the Heating Reactor much less than ordinal power reactor. This feature is beneficial for its application on ships.

(3) High reliability. In main safety systems of the Heating Reactor, there are no rotational components (for example, pumps). This feature improves the reliability of the reactor. As a propulsion reactor, it may work faraway from land base, so the reliability is important.

(4) Simple systems. Because of higher level inherent safety, there is no safety class electro-power source,. As well as high pressure and low pressure injection systems.

Burnable poison is adopted in the reactor, so boron concentration control and regulation system is need no longer.

(5) High Safety. Following features make the reactor more safe during its operation: double pressure vessel, natural circulation (There is no big sized penetration on the pressure vessel), self pressurizer, gravity boron injection and residual heat removing system with natural circulation etc.

This kind of reactor is proper for operation far away from land bases.

3. DESIGN SOLUTIONS

3.1 Design principles

(1) Reactor design will be Improved, but only on the base of existed Heating Reactor design, in order to minimize R & D work. (The Heating Reactor Sections, Systems and parameters are shown in Fig.1-3 and Tab. 1.)

TABLE 1 MAIN PARAMETERS OF THE NHR-200

Reactor power	200MWt	Core power density	36.2kw/L
Coolant pressure	2.5MPa	Height of the core	1.9m
Coolant temperature	210/145℃	Core eq. diameter	~ 1.9m
Pressure of secondary loop	3.0MPa	Number of heat exchangers	6
		Length of the H/Exg.	6.5m
Temperature of 2nd loop	145/95	RPV diameter	5.0m
Temperature of the heat grid	130/80℃	Height	13.6m

(2) Main safety features will be kept: including low pressure, low temperature, low power density and inherent safety systems.

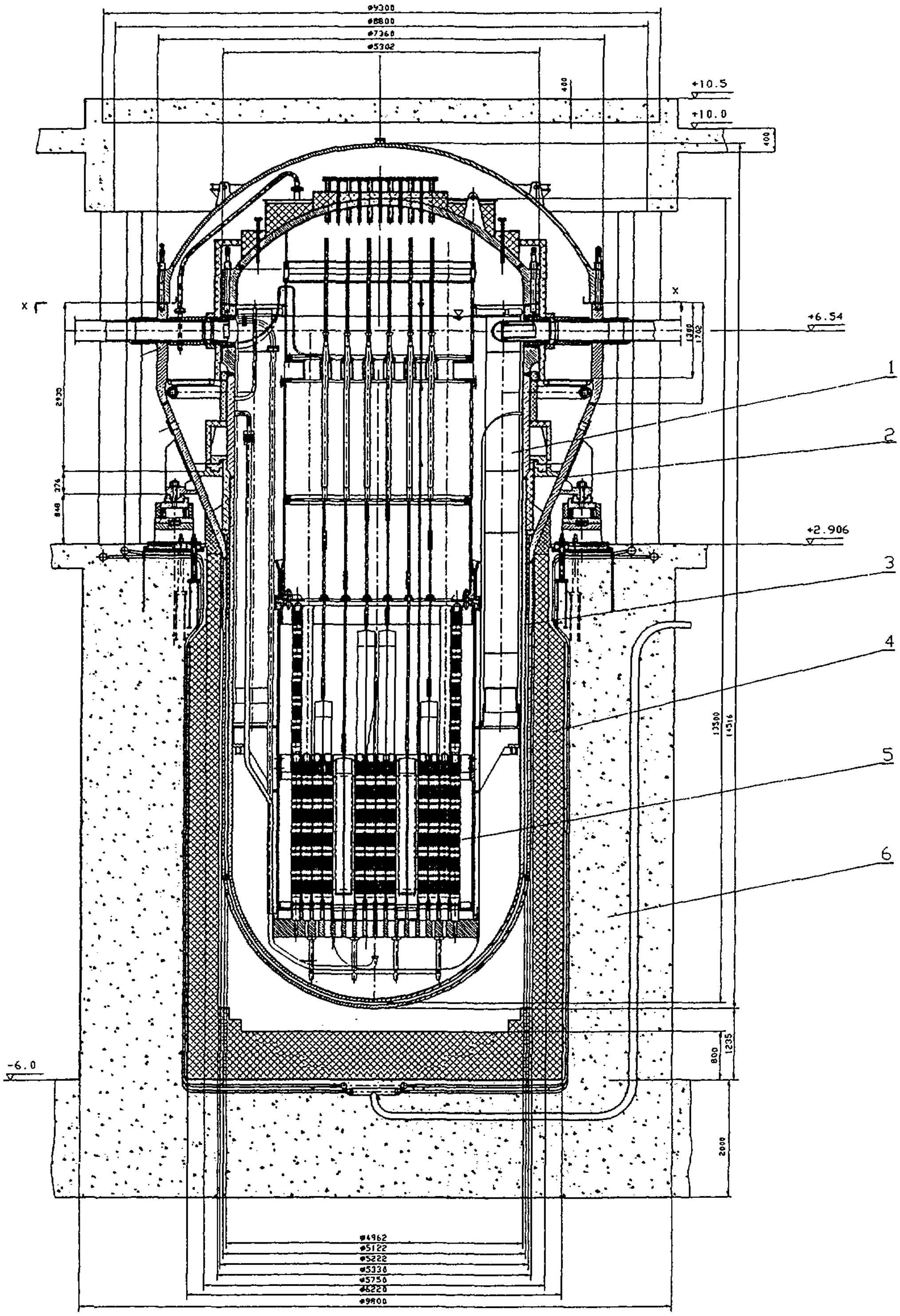
3.2 Main design variants

(1) Back pressure type power and heat cogeneration plant.

Using the heat, generated from the Heating Reactor to drive a back pressure turbine. Then the steam goes to the sea water desalination plant to produce fresh water.

The temperature at the outlet of the reactor core is 213℃.the in let temperature is 154℃, in the case of fresh water productivity=$1.2 \times 10^5 m^3$/day. The power can be used for propulsion is about 12000KW.

Main parameters of the cogeneration plant are as follows (see Tab. 2):



1-main heat exchanger; 2-containment; 3-RPV;
4-thermal isolation; 5-reactor core; 6-biological shield.

Fig. 1 Section of 200MW heating reactor

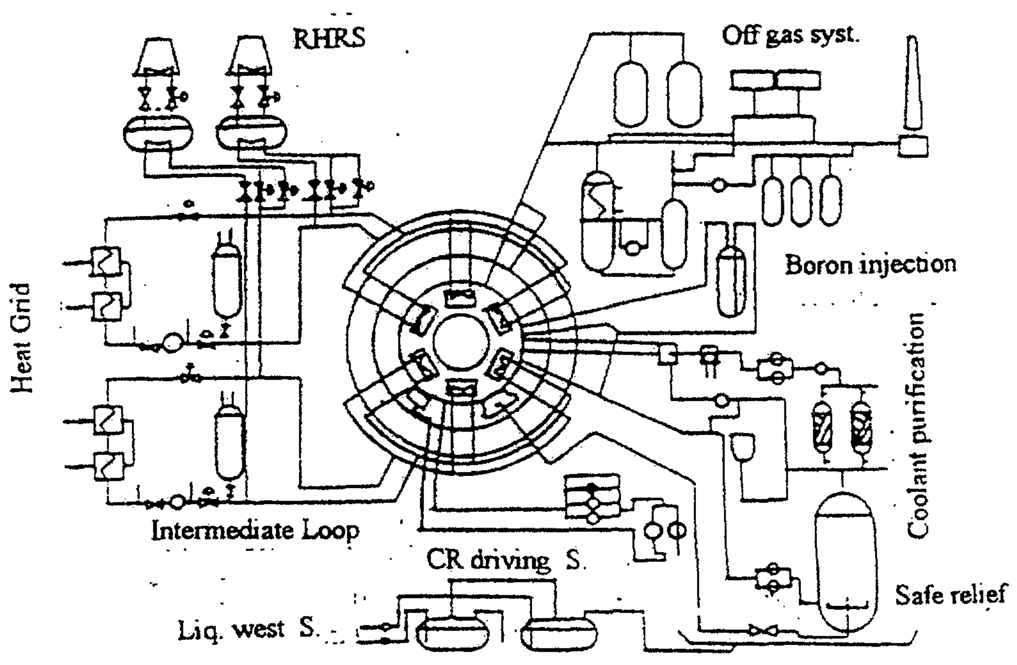


Fig. 2 Schematic System Diagram

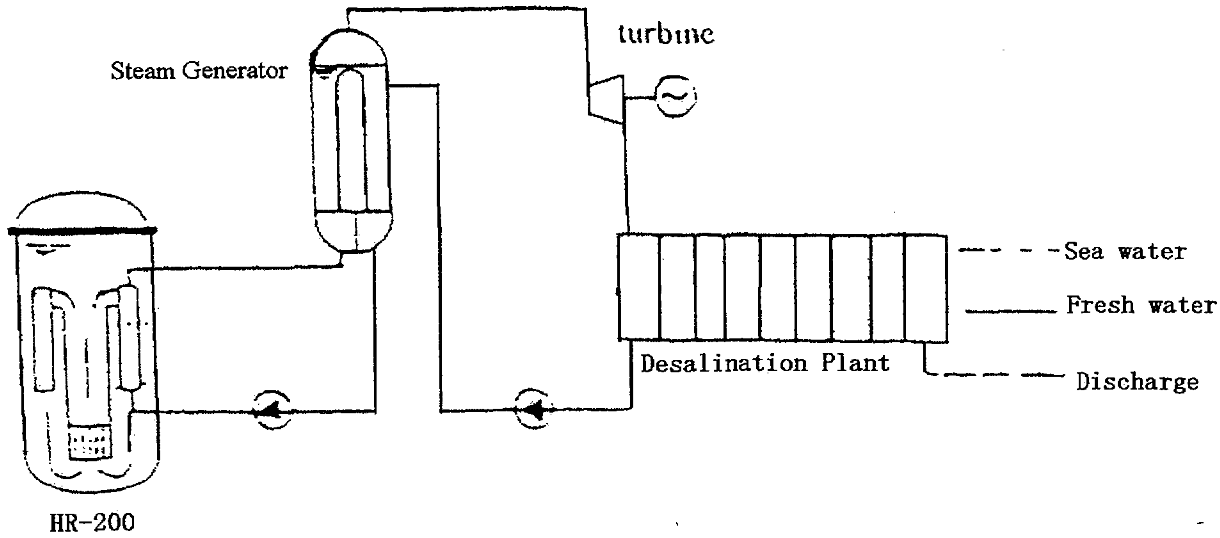


Fig. 3 Back Pressure Cogeneration Plant

TABLE 2. MAIN PARAMETERS OF THE BACK PRESSURE TYPE POWER-DESALINATION PLANT

Reactor power	200MWt	Intermediate loop water temperature	170/144℃
Electro-power	12MWe	Steam temperature	140℃
Pressure of primary loop	2.5MPa	Maximum sea water temperature	105℃
Water temperature at the outlet of the core	213℃	Water productivity	$1.2 \times 10^5 m^3$/day.

(2) Reactor with once through steam generator in the RPV.

In this variant core construction and reactor power are the same as for the Demonstration Heating Plant. That means the reactor power is 200MW. Steam content is about 1%. Pressure of the coolant increases to 4.1MPa, and water temperature at the outlet of the core is 252 ℃ . In the RPV, Once Through Steamgenerator (OTSG) instead of the main heat exchangers for the Heating Reactor.

Steam produced from the steamgenerator can be used for propulsion or electrogeneration, It also can be used for sea water desalination.

When the steam produced from OTSG is used for sea water desalination. It goes to a desalination plant steam generator. Where the secondary steam (pressure of the secondary steam is P=1.72MPa and temperature is 205 ℃) is produced and used for desalination. Its condensate goes back to the plant steamgenerator with temperature 120℃. In this case the intermediate loop is working as a separating loop.

When the reactor is working as a power plant, the saturated steam with pressure P=1.9MPa goes to the turbine. At the full power, the electrogeneration efficiency is about 28%. The maximum power is 55MW.

Main parameters of this solution are shown in the Tab. 3.

TABLE 3 MAIN PARAMETERS OF THE ONCE THROUGH STEAM GENERATOR PLANT

Reactor power	200MWt	Steam content of the core outlet	~ 1%
Elect. power (max)	55MWe	Water temperature at the core outlet	135℃
Pressure of the plant steam	1.72MPa	Steam pressure before turbine	1.9MPa
Temperature of the plant steam	205℃	Steam temperature before turbine	210℃
Steam productivity	275T/h	Feed water temperature for the plant SG	120℃
Return water temperature	80℃	power Efficiency	0.28
Water temperature of the core outlet	252℃		

(3) Cogeneration plant with a boiling water reactor.

In this variant boiling is introduced in the 200MW demonstration Heating Reactor design.

Introduction of boiling instead of the once through SG simplified construction. and gave the maximum power efficiency at the lowest pressure.

In the design the pressure increases to 4.1 MPa, steam temperature is 252℃. Power efficiency reached 32%. The water temperature at the core inlet is 204℃. At the same time part of reactor water is parallelly leaded to a steam generator. Secondary steam (pressure 1.72MPa, temperature 205℃) can be used for sea water desalination.

Main parameters of the plant are shown in Tab.4:

TABLE 4 MAIN PARAMETERS OF THE COGENERATION PLANTS WITH A BWR AND A SL

Items	Pl. with a BWR	Pl. with a SL
Reactor power	200MWt	200MWt
Elector- power	62MWe	47MWe
Elector- Generation efficiency	0.32	0.24
Reactor steam pressure	4.1MPa	4.1MPa
Reactor steam temperature	252	252
Water temperature at the core inlet	204℃	204℃
Heating plant steam pressure/temperature	1.72MPa/205℃	
SG pressure	1.72MPa	1.42MPa
Separating loop pressure		4.2MPa
Separating loop temperature		247/195℃

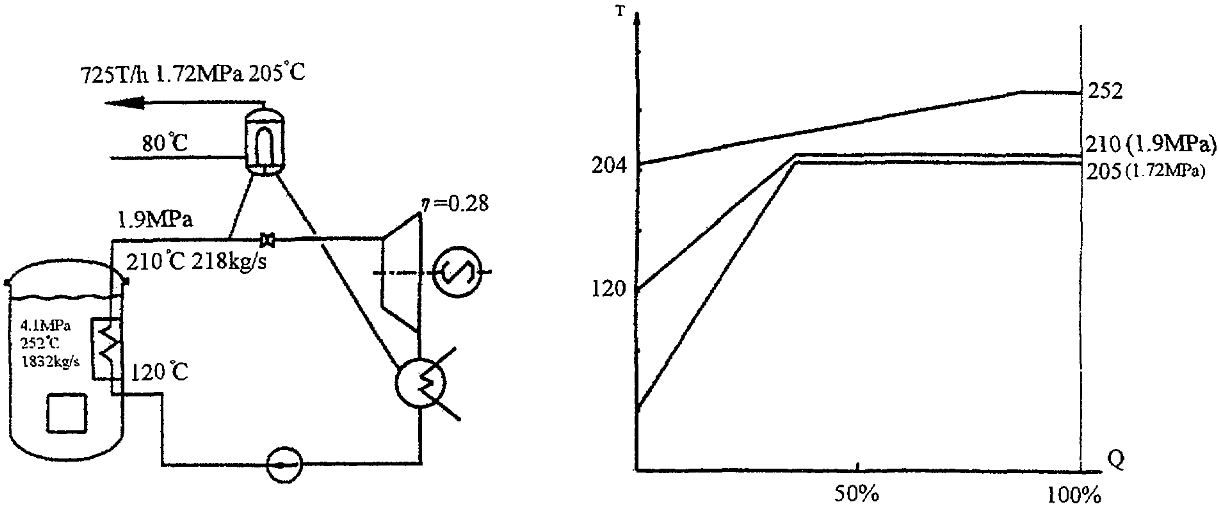


Fig. 4 Cogeneration Plant with OTSG

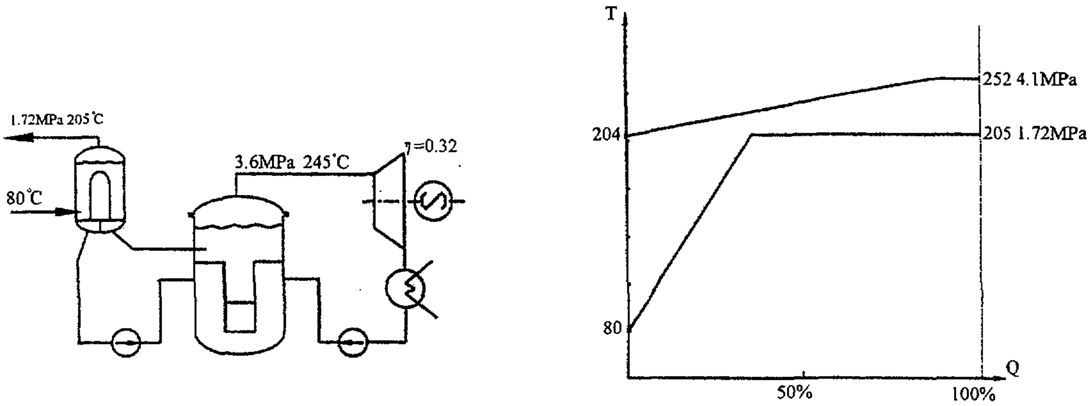


Fig. 5 Cogeneration Plant with BWR

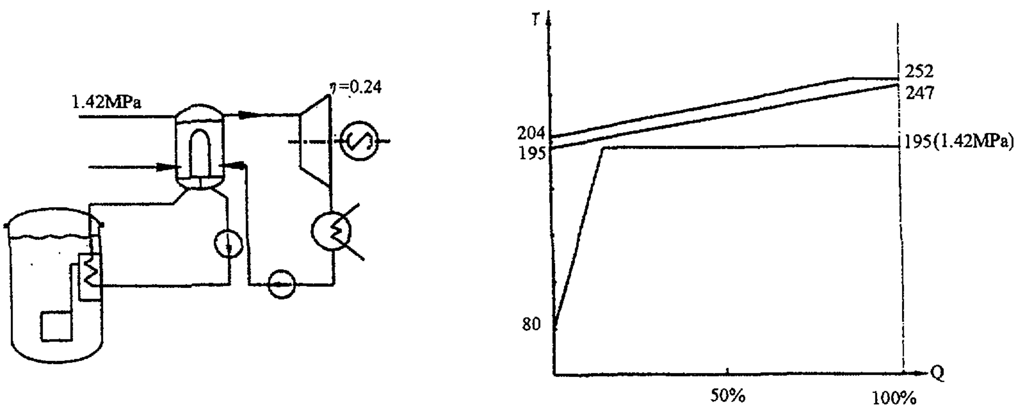


Fig. 6 Cogeneration Plant with a Intermediate Loop

(4) Cogeneration plant with a Separating loop.

In order to effectively separate the power loops from reactor radioactive primary loop,. as in the Demonstration Heating Plant, a intermediate loop solution is adopted in this design variant.

In this variant, reactor work pressure increased to 4.1 MPa. Steam content at the core outlet is about 1%, water temperature 252℃. At the core inlet water temperature is 204℃.

Secondary loop is a separating loop, its pressure 4.2MPa, consisted of main heat exchanger, steam generator (SG) and circulating pumps. In the primary side of the SG temperature are 247/195 ℃, in the secondary side the steam pressure is 1.42MPa, temperature 195 ℃ . Part of steam is used for power generation. The other part of steam is used for desalination or heating. Quantity of heat and power can be regulated by a distribution valve.

If all steam is used for power generation, the maximum power is 47MW and elector-generation efficiency is about 24%.

This variant is more close to the existed Heating Reactor design. Changes are very small. Radioactive water leakage is almost impossible and power productivity is enough high.

Main parameters of the cogeneration Plant with a Separation Loop (SL) are shown is Tab. 4.

4. COMPARISON AND CONCLUSION

In above variants, the first one under the same pressure (≐2.5MPa) as for the existed Heating Reactor design, the reactor can supply some quantity power, but the quantity is small and power efficiency is low (see variant (1)).

If pressure is increased to 4.1MPa, and boiling is introduced in the reactor core, the power productivity will be reasonable increased. In these variants the variant with separating loop more close to original Heating Reactor design. It will be easier to go through the license procedure. But it power efficiency only about 24%.

Once Through Steam Generator variant gives a higher efficiency of but the height of the reactor will be increased, because the steam generator is longer than original heat exchanger.

Boiling water reactor variant gives highest efficiency. But introduce of boiling with a lower pressure requires some additional R & D work. The construction of the core has to do some changes.

At the time being we are working for the variant with a separating loop.