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Investigation on three seawater desalination processes coupled with NHR-200

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ABSTRACT

NHR-200, an integrated nuclear reactor with thermal power of 200 MW is developed by INET. Coupling NHR-200 with three kinds of desalination processes, low-temperature horizontal tube MED-TVC, high-temperature stacked VTE-MED and a hybridization of reverse osmosis and MED have been investigated and compared. The capacities of the fresh water production are 107,500 m^3/d 160,000 m^3/d, and 250,000 m^3/d respectively. This paper presents the main features of the reactor, interface consideration between the reactor and desalination plant, and the preliminary economic analysis results. The hybrid RO/MED process showed the best economic competition.

1. Introduction

With the rapid development of economics and society, nowadays China, particularly northern China is facing severe problems of fresh water shortage. The situation in Shandong peninsula is particularly grim. Its freshwater resource per capita is only one sixth of the national average value and one twentieth of the worldwide average value. The Chinese central and local government pays a lot of attention on the fresh water shortage problems and has initiated a very large water transfer project that is transferring water from South to North. Although this project is very grand and ambitious, it can't solve all fresh water shortage problems in north China. Therefore, seawater desalination has been considered as an important measure to mitigate freshwater shortage for cities along the eastern coast of China.

Based on the worsening freshwater shortage worldwide, the International Atomic Energy Agency (IAEA) has addressed the issue of seawater desalination for potable water production since 1989, and renewed interest in seawater desalination using nuclear energy [1,2]. It has been found that there are no technical impediments to the use of nuclear reactors as an energy source for seawater desalination.

Aiming to provide a potential solution on the grim situation in freshwater shortage of Shandong peninsula of China, and in order to disseminate the concept of the nuclear desalination technology and to verify its technical feasibility and economic viability, the feasibility study of the Shandong nuclear desalination plant (SNDP) [3,4] had been carried out. The integrated nuclear desalination system consists of an integrated nuclear reactor with thermal power of 200 MW, a desalination process and common facilities. The comparative investigation of three schemes, respectively coupling 200MWth integrated nuclear reactor with low-temperature horizontal tube evaporator MED-TVC or with high-temperature vertical tube evaporator VTE-MED or with hybridization of RO and MED, has been carried out in the feasibility study.

2. 200MW Integrated Nuclear Heating Reactor

The NHR-200 is developed mainly based on the experience gained from the design, construction and operation of NHR-5 [5] by the Institute of Nuclear Energy Technology (INET) of Tsinghua University. NHR-200 is water coolant, integrated, full-power natural circulation reactors with passive safety features.

2.1. Main design of NHR-200

The NHR-200 has been designed with a number of advanced and innovative features to achieve its safety goal and economic viability [6–8]. No off-site emergency actions such as sheltering, evacuation, relocation and decontamination are the general safety requirement in case of all credible accidents.

That the core is always covered by coolant is one of the fundamental design criteria for NHR-200. Both reactor system and the primary circuit, including primary heat exchanges, are arranged into the reactor pressure vessel. The core is located at the bottom of the RPV, and primary heat exchanges are arranged within the annular space between the riser and vessel wall. The riser is to enhance the capability

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of natural circulation. The main structure of NHR-200 is shown in Fig. 1.

The core of the NHR-200 is composed of fuel assemblies with the fuel boxes and cruciform control rods. The initial fuel loading is 18.0 tons. Gadolinium oxide is used as a burnable poison to control the reactivity along with the B_4C control rods. The reactor coolant does not contain boric acid during normal operation.

In the NHR-200, the heat produced in core is transferred via the primary circuit and the intermediate circuit (IC) to the steam supply circuit (SSC). The motive steam is saturated steam and will be supplied to the desalination plant. The motive steam will be condensed by the seawater within the first effect of the MED and then flows back to the steam generators as its feed water. Stable steam supply is important for thermal desalination plant. Steam generator of NHR-200 adopts invented U type structure. This type's design could ensure to avoiding thermodynamic instability. The main design parameters of NHR-200 are shown in Table 1.

2.2. Main design of NHR/M-200

Aiming to couple with RO desalination system, NHR/M-200 is developed by INET based on NHR-200. The same as NHR-200, that the core is always covered by coolant is also one of the fundamental design criteria for NHR/M-200. Both reactor system and the primary circuit, including steam generators, are arranged into the reactor pressure vessel (RPV). The core is located at the bottom of the RPV, and steam generators are arranged within the annular space between the riser and vessel wall. The riser is to enhance the capability of natural circulation.

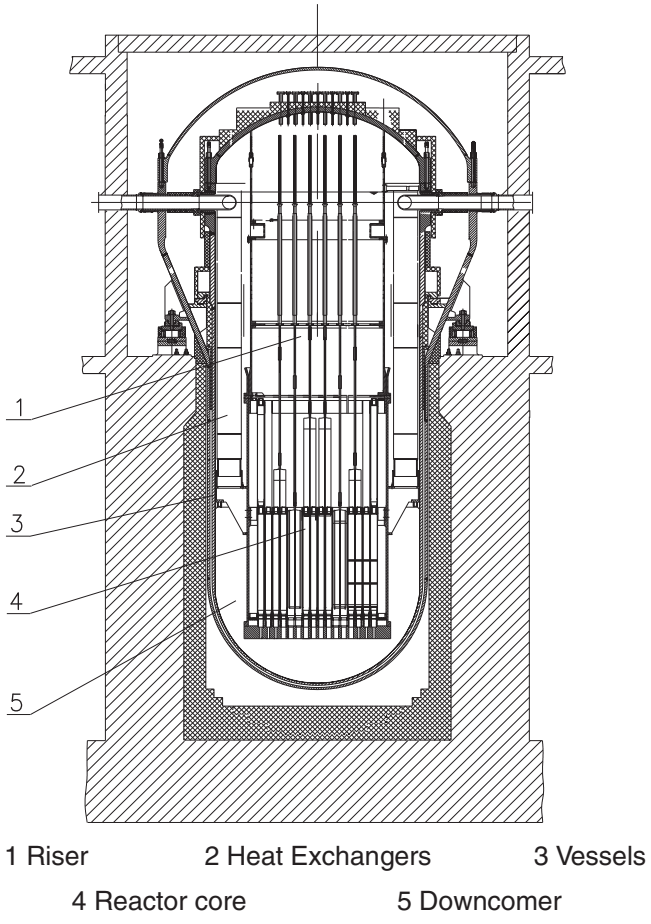

Fig. 1. Reactor structure of NHR-200.

Table 1
Main design parameters of NHR-200.

Parameter name	Unit	NHR-200
Reactor thermal power	MW	200
Primary circuit pressure and reactor core	MPa	2.5
Core temperature inlet/outlet	°C	155/212
Intermediate circuit pressure	MPa	3.0
Temperature of intermediate circuit	°C	135/165
Steam pressure	MPa	0.24
Steam temperature	°C	126

In a seawater RO system power cost is the largest component to cost of product water. In order to decrease desalted water cost, electric power should be generated when nuclear heating reactor couple with RO desalination system. NHR/M-200 in SNDP is used as the only energy source for plant, mainly for reverse osmosis (RO) process. The heat in core is transferred from the primary circuit to the steam supply circuit through steam generators. Then through steam-water separators the motive steam will be obtained. The motive steam is also saturated. But the pressures of primary circuit and steam are higher than NHR-200's. The steam will be supplied to turbine to generate electric power. The main design parameters of NHR/M-200 are shown in Table 2.

2.3. Safety feature of nuclear heating reactor

For the nuclear heating reactor, it should be located in the vicinity of the user due to the consideration of heat transportation and economy. The distance between the reactor and the populous area is not a protecting factor any longer. Therefore, no off-site emergency actions such as sheltering, evacuation, relocation and decontamination are the general safety objectives in case of all credible accidents. In other words, the radioactive release from the NHR has to be reduced to such low levels that off-site emergency actions are not necessary. To meet the requirements of the general safety objectives, a series of technical measures are adopted in the design of the NHR.

The safety concept for the NHR fundamentally based upon its inherent and passive safety characteristics rather than the engineered safety features, so a higher standard in its safety and reliability will be well achieved.

(1) Reactor self-protection ability and shutdown concept

The large negative reactivity coefficients have been achieved in the NHR nuclear design, so that the reactor possesses strong self-protection ability, including self-control and self-limitation in core power. Meanwhile, there are no any large reactivity additions in the NHR owing to the unique features of the control rod driving mechanism and a great inertia in the primary system. Therefore, any transients and accidents, including uncontrolled reactivity additions, LOCA and ATWS, will be very well counteracted.

(2) Provisions for preventing core from uncovering

It is one of fundamental design criteria for the NHR that the reactor core should be always covered by coolant under any conditions. With the purpose, some provisions have been incorporated into the NHR design, such as that the NHR is designed with natural circulation

Table 2
Main design parameters of NHR/M-200.

Parameter name	Unit	NHR/M-200
Reactor thermal power	MW	200
Primary circuit pressure	MPa	8.0
Core temperature	°C	238.6/285
Steam supply pressure	MPa	3.2
Steam temperature	°C	237.5