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INTEGRAL VESSEL TYPE NUCLEAR HEATING REACTOR AND ITS FEATURES IN TECHNOLOGY

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ABSTRACT

The 5MW Nuclear Heating Reactor (NHR), developed by INET, is a new vessel type light water reactor with natural circulation and integrated arrangement. It was put into operation at the end of 1989. The experience from four winter operations has shown that all technical indexes are satisfying enough as expected in the design. The good overall performance and availability of the 5MW NHR have showed that this kind of heating reactor would be an ideal heat source for district heating in urban area.

1 INTRODUCTION

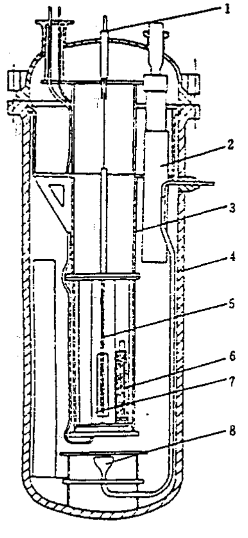
The 5MW NHR is a new type of reactor with good inherent safety. A series of advantage techniques were adopted as follows, the integrated arrangement, the self-pressurized maintenance, the full power natural circulation, the passive residual heat removal system and the new type of control rod hydraulic drive system. The reactor construction started in 1986 and full power operation was reached in 1989. Up till now, the 5MW NHR has successfully supplied heating for four winters. At the same time, the experiments on refrigeration for air conditioning and co-generation of heating and power were made. What the reactor operating results showed is in the following:

(1) The main operating parameters reached or exceeded original design targets (See Table 1).
(2) The reactor has a high heating availability, and the ratio between real operating time and design operating time exceeded 99%.
(3) The transient and stationary operating experiments showed the reactor was in good inherent safety and power self-regulation. It would be shut down by itself based on its physical features even if the reactor was at the full loss of heat sink and shutdown failure of control rod system.

2 5MW NHR FEATURES AND ITS EVALUATION

(1) Integrated arrangement design

The 5MW NHR is designed with an integrated arrangement. The main facilities of the primary loop, such as the core, internals, main heat exchangers, mechanism of hydraulic drive control rods, are all arranged in the pressure vessel (Fig. 1).



1.Ultra-sonic sensor 2.Main heat exchanger
3.Core barrel assembly 4. Pressure vessel
5.Control rod 6. Fuel assembly
7.Core 8. Boron injection nozzle

Fig. 1 5MW NHR

The internal of the reactor is a hanging-up structure and the reactor core rests on the bottom of the barrel. The safety of the reactor rises because of the integrated arrangement that canceled external large sized pipes and so there is no possibility of LOCA in the event of main pipe break.

The technical difficulties of the integration are not only in the accuracy fitting of the components within the vessel under the high temperature and high neutron irradiation, but also in the integrated arrangement of structures, especially in the combination of the flow channels of coolant, the overhauling and replacing main exchangers, the sealing of the closure head and the barrel of the pressure vessel, etc. A satisfactory solution for these technical problems was gained during designing and building the 5MW NHR. Four year operating experience has shown the success in the design of integrated structure and its sealing techniques.

(2) Self-pressurized maintenance feature

The control of the operating pressure is made by using of the principle of partial pressure of steam and non-condensable gas N_2. It omitted completely an external heating pressurized system, and good pressure stability was proved in operating period.

One of the design features of the 5MW NHR is to keep the reactor outlet temperature in stable when external load changes, so do steam partial pressure and N_2 gas partial pressure. Those made the reactor pressure keep on the relative stable level (See Table 2).

(3) Cooling of full power natural circulation

The 5MW NHR has realized the full power natural circulation. The circulating cooling is ensured more reliable even if total loss of electric power occurs. In order to reduce the resistance of natural circulation, the main heat exchangers with lower flow resistance were researched and designed. The experiments prove that the flow resistance is only ten percent of the normal heat exchangers.

(4) Hydraulic drive system and ultra-sonic position indicator system

The 5MW NHR used the hydraulic step cylinder control rod drive instead of electric-magnetic or mechanism drive system for PWR. A pulse valve driven by hydraulic dynamics and a special power source were adopted too, so the rod drive has the following good features:

(a) Because only one rod can be raised a step every time, there is no possibility to cause big reactivity disturbance.
(b) The system is with short drive chains and reaches good system reliability.
(c) The simplified structure decreases the height of reactor.
(d) The "fail-safe" design rules out the possibility of rod ejection under de-pressurization and water loss of coolant.

The ultra-sonic indicator is designed to indicate the position of control rods. The ultra-sonic technique was adopted in the measurement of the control rod position for the first time. This system includes ultra-sonic sensors of heat and radiation resistance, and some instruments for signal distinguishing and measurement. The positions of rods can be displayed by the lights, digital and simulated curves on the CRT. During the operating period, it shows that the rods can insert to the core rapidly when shutdown occurrs and the ultra-sonic indicator can work accurately.

(5) Double pressure vessels

A containment fits tightly around the outside of the main pressure vessel so that the coolant in the pressure vessel can flood the core even if the pressure vessel was broken.

(6) Passive residual heat removal system

A passive system of residual heat removal is adopted in the 5MW NHR. The system carries the residual heat to the extreme heat sink -- the atmosphere depending on natural circulation (See Fig. 2). The operating results show that the system can work immediately on the natural circulation and then transfer the residual heat out from the reactor at any shutdown event. Even if the primary loop is broken, the system still can transfer the total residual heat by its condensing capability.

(7) Boron injection system

The boron injection system is the second shutdown system which was designed specially in the 5MW NHR. If the primary loop was broken, the siphonage would have been interrupted to prevent the core from the loss of water. The experimental results have shown that the new type system's function is effective.

(8) Self-regulation and load follow features

In order to get higher self-safety and better self-stability, the reactor is designed with a large negative temperature coefficient and bubble reactivity coefficient in the physical design . The loss of main heat sink-ATWS experiment has shown that the reactor could shut down automatically on the base of the negative temperature coefficient.

(9) Protection shutdown system and computer information processing system

Protection shutdown system is designed as simple and reliable as possible which is based on the principle of single failure, the principle of fail-safe and the principle of independent safety. At the same time, the feature of the on-line monitoring is set to increase the safety. The computer processing system with its graphic displaying features makes the operation at a high reliability level.

3 THE OPERATION EXPERIENCE OF 5MW NHR

The operating experiences and many experiments have proved sufficiently that the reactor has good operating features and safety characteristics.

(1) Load follow feature under normal operation conditions

In order to research the load follow capacity and self-regulation of the 5MW NHR, the flow in first side of intermediate heat exchangers was changed to simulate the rapid change of the external load and, at the same time, the control rod position was kept stable. In fig. 4, showed is the coolant system diagram. The flow of intermediate heat exchangers was increased from 8t/h to 35t/h, then dropped back to 8t/h, which simulated the load of heat grid waved from 1530 kW to 2530 kW, then to 1530 kW (i.e., the load changed about 66%). Owing to the feedback of the negative reactivity coefficient, the reactor power followed after 90 seconds, and about 30 minutes later it was stablized on a new power level needed (See Fig. 5). In this process, the reactor outlet temperature only changed about 2-3°C, and the reactor pressure varied a little. The result shows that the 5MW NHR has a good load follow feature.

(2) Loss of main heat sink -- ATWS

The ATWS experiment for the loss of heat sink has been made when the power was at 2MW stationary operation condition (Fig. 6). In the experiment, the heat grid been cut off to simulate the loss of heat sink, and the position of the control rods kept at the original place, the reactor power decreased from 2MW to 0.2 MW gradually due to the feedback of the negative temperature reactivity coefficient, and maintained on a low level. In the experiment, when the inlet water temperature increased 20.4°C, outlet water temperature increased 4.7°C, and then the pressure raised 0.23 MPa. It shows that the offsets of system parameters will still be in the acceptable range even if the serious accident occurrs.

(3) Residual heat removal feature

It is very important for the reactor to remove residual heat reliably. Two independent and passive residual heat transport systems are adopted. Without any active energy source, the systems can transport the reactor residual heat to the surrounding environment reliably (See Fig. 3). The operating results show that the capacity of every real cooling system can reach 116 kW which exceed the design value of 75 kW. In fig. 7, the curves of residual heat removal after shutdown are illustrated.

A special experiment shows that the residual heat removal system can still work normally and transport the core residual heat reliably on condensing heat transferring in the main heat exchangers, even if the reactor water level drops down to the level leading to the interruption of natural circulation, i.e., the loss of coolant accident.

4 CONCLUSION

The 5MW NHR is second generation nuclear facility with a number of advanced technique features. Its successful operation will be helpful to the design, construction and operation of a large scale demonstration NHR. The Chinese government has decided to design and construct a 200MW NHR in China before 1997 or 1998.

The 5MW NHR, with the features of inherent safety, simplification in structure, good economic characteristics and low investment as well as short construction period, is very suitable for the Chinese present economy and technology status. The prospect for developing NHR in China is very promising.

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Table 1. Main operating parameters of 5MW NHR

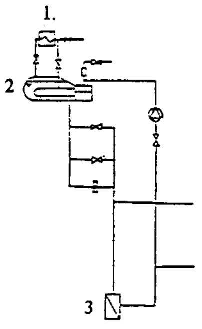
Parameter	*Unit*	*Design value*	*Operation value*
Thermal power	kW	5000	5000
Core outlet temperature	°C	186	186
Core inlet temperature	°C	146.6	155*
Main heat exchanger			
Inlet temperature of 2nd side	°C	102	100
Outlet temperature of 2nd side	°C	142	143
Flow of 2nd side	t/h	107	95
Intermediate heat exchanger			
Inlet temperature of 2nd side	°C	142	142
Outlet temperature of 2nd side	°C	75.2	80
Flow of 2nd side	t/h	64	66
Heat grid			
Supplied temperature	°C	90	82
Return temperature	°C	60	56
Primary system pressure	MPa	1.37	1.37
Water lever of pressure vessel**	mm	1000	1000

* Core inlet temperature is higher than the design value. It shows that the capacity of reactor natural circulation exceeded the design feature.

** The level is over the bottom of the vessel 5220 mm.

Table 2. Reactor Parameters Change with the External Grid Load

Parameter	*Measure values*			
	Unit	*Before change*	*After change*	*Relative fluctuation(%)*
Heat grid load	kW	1531	2536	66
Reactor power	kW	1664	2629	58
Core inlet temperature	°C	160.2	152.9	4
Core outlet temperatures	°C	177.9	176.4	0.8
Reactor pressure	MPa	1.32	1.23	0.7



1. Aircooler 2. Steam generator
3. Main heat exchanger

Fig. 2 Diagram of residual heat removal system of 5MW NHR

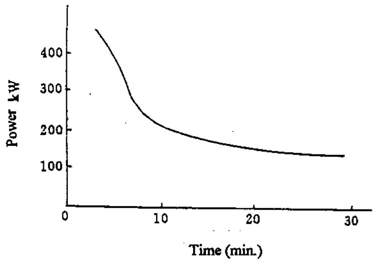
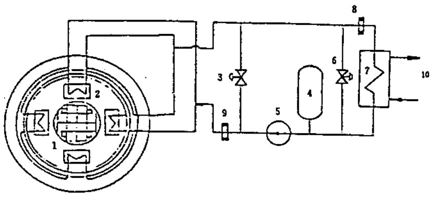
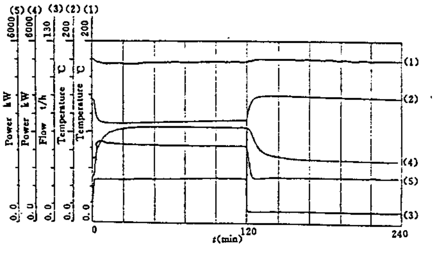


Fig. 3 Experimental curve of residual heat removal system



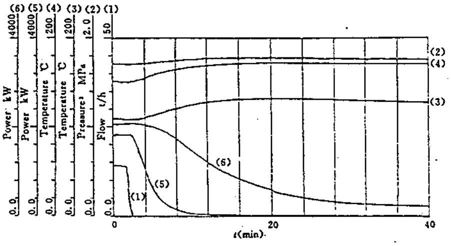
1. Core 2. Main heat exchanger(MHE)
3. MHE bypass valve 2130
4. Pressure controller 5. Circulating pump
6. Intermediate heat exchanger(IHE) bypass valve 2170
7. IHE 8. IHE regulator Q_{214} 9. MHE regulator Q_{212}
10. Heat grid

Fig. 4 Cooling system diagram



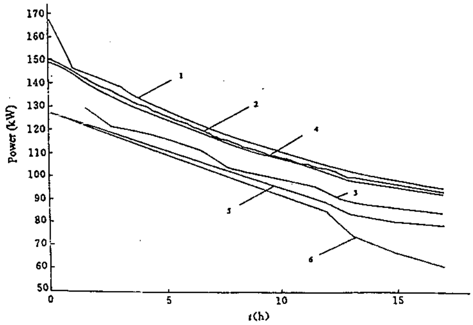
1. Core outlet temperature, °C
2. Inlet temperature of 2nd side of MHE, °C
3. Flow of 2nd side of IHE, t/h 4. Reactor power, kW
5. Power of heat grid, kW

Fig. 5 Load-power follow feature



1. Flow of 2nd side of IHE, t/h 2. Reactor pressure, MPa
3. Core outlet temperature, °C 4. Core inlet temperature, °C
5. Power of heat grid, kW 6. Reactor power, kW

Fig. 6 Loss of main heat sink -- ATWS



1.Core outlet temperature 2.Core inlet temperature
3.Steam generator outlet temperature 4.Steam generator inlet temperature
5.Aircooler inlet temperature 6.Aircooler outlet temperature

Fig. 7 Experiment of 5MW NHR shutdown cooling