DESIGN PRECAUTIONS FOR COUPLING INTERFACES BETWEEN NUCLEAR HEATING REACTOR AND HEATING GRID OR DESALINATION PLANT

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Abstract

Nuclear heating reactor (NHR) has been developed by INET since the early eighties. To achieve its economic viability and safety goal, the NHR is designed with a number of advanced and innovative features, including integrated arrangement, natural circulation, self-pressurized performance, dynamically hydraulic control rod drive and passive safety systems. As a new promising energy system, the NHR can serve for district heating, air conditioning, sea-water desalination and other industrial processes. For all of these applications, it is vital that the design and performance of the coupling interfaces shall insure protection of user ends against radioactive contamination. Therefore, an intermediate circuit is provided in the NHR as a physical barrier, and the operating pressure in the intermediate circuit is higher than that in the primary system. In addition, the radioactivity in the intermediate circuit is monitored continuously, and there are also other protection measures in the design for isolating the intermediate circuit and the heating grid or desalination plant under some emergency conditions. The excellent performance of the above design precautions for the coupling interfaces has been demonstrated by operational practice from the NHR-5, a 5MW(thermal) experimental NHR, which was put into operation in 1989. This paper presents the main design features of the NHR as well as the special provisions taken in the design for coupling the NHR to the heating grid or desalination plant and some operating experince from the NHR-5.

1. Introduction

Research work on the possible applications of nuclear power for low temperature heating was initiated in the early eighties. During 1983-1984 Institute of Nuclear Energy Technology (INET) of Tsinghua University used its existing pool-type reactor to provide space heat for nearby buildings. Meanwhile, two reactor types, a deep pool type NHR and a vessel type NHR were developed by INET. Based on the specific heating needs in China and a comparison of various NHR design concepts, the vessel type NHR was selected as the main development direction. As a result, construction of a 5MW (thermal) experimental NHR (NHR-5) started in 1986 at INET. The reactor was successfully put into operation for space heating in 1989.

Since 1990, a commercial sized NHR with an output of 200 MWt (NHR-200) has been developed, and it was approved by the central goverment in 1995 that an NHR-200 demonstration plant would be built in Daqing in Northeast China. The NHR can be used in district heating, sea-water desalination, air conditioning and other industrial processes. For all of these applications, there is a risk of radioactive contamination to user ends. Therefore special design considerations should be given to the coupling interfaces between the NHR and the heating grid or desalination plant.

The main purpose of this paper is to present the NHR technical description as well as the design precautions for the coupling interfaces and the operating practice from the NHR-5.

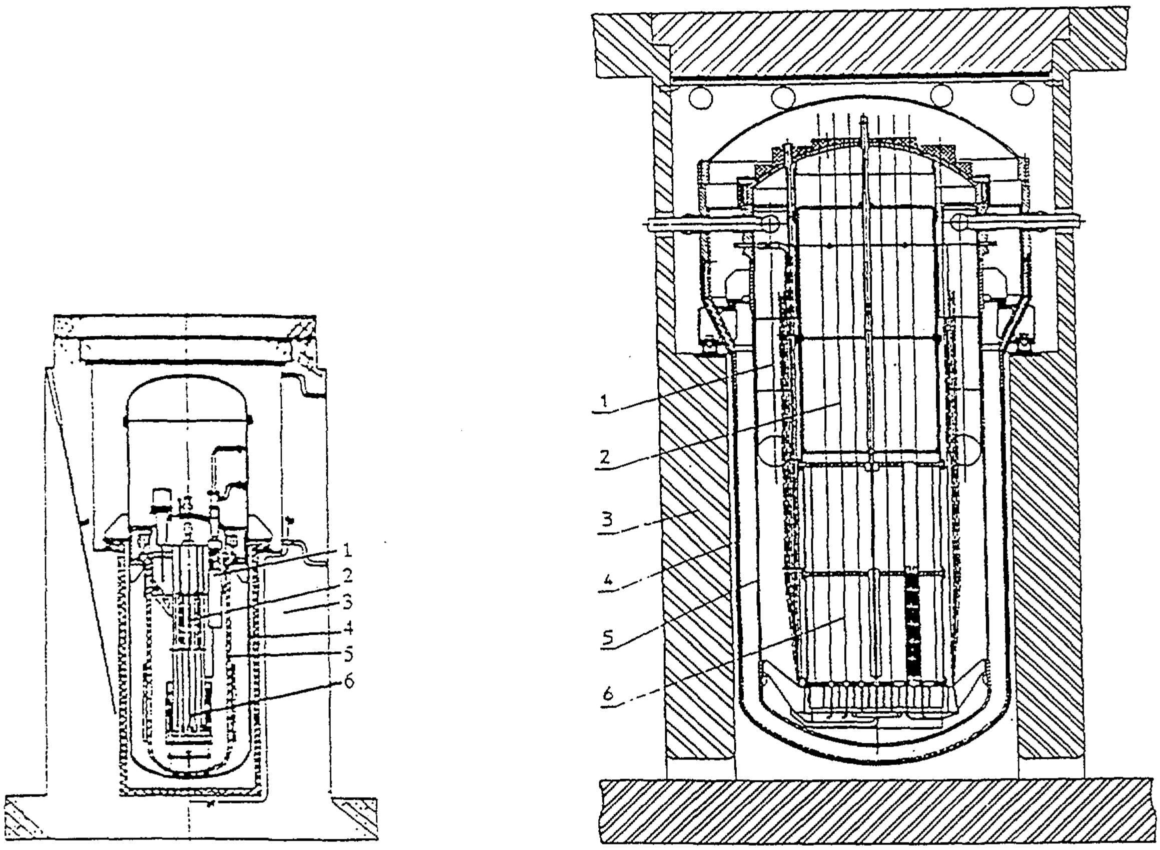
2. Technical Description of the NHR

The NHR has been designed with a number of advanced and innovative features to achieve its safety goal and economic viability. Fig.1 (a) and (b) show the reactor structures of the NHR-5 and the

NHR-200, respectively. Their essential design features are the same. The NHR is a vessel type light water reactor with an integrated arrangement, natural circulation, self-pressurized performance and dual vessel structure. The core is located at the bottom of the reactor pressure vessel (RPV). Primary heat exchangers (PHEs) are arranged on the periphery in the upper part of the RPV. The system pressure is maintained by inert gas and/or steam. A containment vessel fits tightly around the RPV so that the core will not become uncovered under any postulated leakage in the reactor coolant pressure boundary. The reactor coolant circulates due to density differences between "hot" and "cold" regions in the RPV. There is a long riser on the core outlet to increase the natural circulation capacity.

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. The dynamically hydraulic control rod drive system used in the NHR is designed on the "fail-safe" principle. i.e. control rods will drop into the reactor core automatically upon loss of power supply, depressurization, pipe break and pump shutdown events.

Spent fuel assemblies are stored in racks around the active core. This solution greatly simplifies the refueling equipment.



(a) NHR-5

(b) NHR-200

1. Primary Heat Exchanger
2. Riser
3. Biological Shield
4. Containment
5. Pressure Vessel
6. Core

Fig.1 Cross Section of NHR

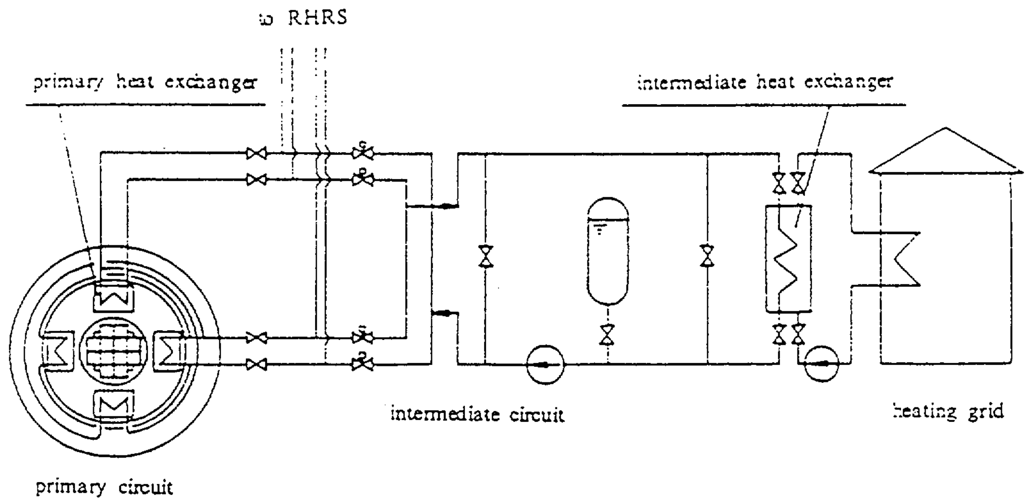


Fig.2 Schematic Diagram of NHR-5 Heat Supply System

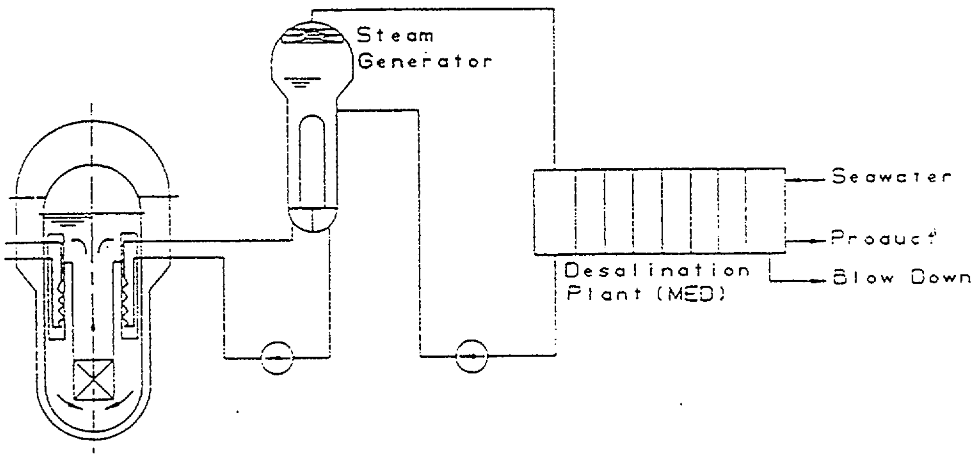


Fig.3 Schematic Diagram of NHR Coupled with H-MED

A simplified schematic diagram of the NHR used for district heating and for the desalination are shown in Fig.2 and Fig.3, respectively. The nuclear heat supply system contains triple loops. The primary coolant absorbs heat from the reactor core, passes through the riser and enters the PHEs where the heat is transferred to the intermediate circuits. Finally, heat is delivered to the heating grid via an intermediate heat exchanger or to the desalination plant via a steam generator. An intermediate circuit is needed in the NHR to insure that the heating grid or the desalination plant is free of radioactivity.

There is no emergency core cooling system in the NHR. The residual heat removal system (RHRS) is the most important safety system for the NHR and is designed as a passive system. The decay heat will be dispersed into the ultimate heat sink by natural circulation. A boric acid injection system, as a secondary reactor shutdown system, will be operated by gravity if an anticipated transient without scram (ATWS) occurs.

The key NHR design data is presented in Table I.

Table I Main Design Data of NHR

Reactor		NHR-5*	NHR-10**	NHR-200*
Thermal power	MW	5	10	200
Primary system pressure	MPa	1.5	2.5	2.5
Core inlet/outlet temperature	°C	146/186	174/210	140/210
Volumetric power density	kW/L	26	23	35.2
Number of fuel assemblies		16	32	96
Number of control rods		13	13	32
Active core height	m	0.69	0.80	1.9
Active core diameter	m	0.57	0.95	1.9
Initial inventory of UO_2	t	0.51	1.4	14.23
Enrichment of initial core	%	3.0	3.0/4.5	1.8/2.4/3.0
Refueling enrichment	%	3.0	3.0/4.5	3.0
Intermediate circuit pressure	MPa	1.7	3.0	3.0
Intermediate circuit temperature	°C	102/142	180/135	95/145
Heat grid temperature (Steam temp.)	°C	90/60	(130)	130/80-90/70***

* NHR for district heating
** NHR for sea-water desalination with H-MED process
*** Temperature in the third and forth loop, respectively.

3. Design Precautions for the Coupling Interfaces

In the present nuclear heat applications, energy is supplied mainly in the form of hot water or low temperature steam. Coupling is accomplished via a heat transmission loop. A major concern for these applications is to prevent radioactivity ingress from the transferring to the heating grid or the product water. To this end, the following design precautions have been taken for the coupling interfaces between the NHR and the heating grid or desalination plant.

(1) An intermediate circuit is provided as a physical barrier in the NHR, so that there are at least two physical barriers generally between the primary system and user ends. As seen in the Fig.2 and Fig.3, the radioactive coolant of the primary system could in principle reach the heating grid or desalination plant only after penetrating the primary heat exchanger and the intermediate heat exchanger or the steam generator in succession. For district heating, there is usually an additional physical barrier provided by the heat exchanger in the local heat distribution station. While in coupling the NHR to a desalination plant with a Multi-Effect-Distillation (MED) process, the first stage of the MED will provide an additional physical barrier to prevent product water from radioactive contamination.

(2) The operating pressure in the intermediate circuit is higher than that in the primary system and the heaitng grid. Therefore, in case of tube failures in the PHEs, the leakage direction is toward the primary side instead of allowing radioactive coolant to leak out. This solution also favors to keep the water quality in the intermediate circuit due to free of contamination from the heating grid.

(3) The pressure and radioactivity of the intermediate circuit are monitored continuously. Either the pressure decreases or the radioactivity increases to a set point, the isolation devices will be triggered to isolate the intermediate circuit. The isolation action can also be done in the heating grid or desalination plant.

The above special design measures for the coupling interfaces will insure protection of the heating grid or the product water against radioactive contamination.

4. Operating Practice of the NHR-5

Since the NHR-5 was put into operation in 1989, a number of experiments have been carried out to demonstrate the operating and safety features of the NHR, including self-regulation and self-stability features, transient behaviour following a loss of main heat sink-ATWS and the heat transfer capability of RHRS with and without interruption of natural circulation in the primary system. Meanwhile, in order to investigate multiple functions for the NHR, experiments were also conducted in the NHR-5 to study concepts such as electricity generation with low pressure steam in a co-generation mode as well as desalination process with high-temperature MED (H-MED) technologies and air conditioning for a large building using the lithium-bromide absorption process.

During reactor operation for space heating and all the above experiments, specific water radioactivity of the intermediate circuit is monitored continuously. However, the specific radioactivity is much lower than the rad-meter sensitivity as no radioactive coolant could penetrate from the primary system. Therefore, to monitor radioactivity in the intermediate circuit and the heating grid can only be performed by reqular sampling analyses. The results of the analyses conducted since 1989 have shown that the specific water radioactivity in the intermediate circuit and the heating grid is as low as the radioactive background level of potable water in the site area, which is about 0.10 Bq/l. Meanwhile, higher standards of water quality in the intermediate circuit can be easily maintained. Analytic radioactivity data in the intermediate circuit are somehow lower than that in the heating grid. Therefore, the operational data and experimental results from the NHR-5 have demonstrated that the overall performance of the NHR is excellent and the design measures adopted for the coupling interfaces function properly.

5. Conclusive Remarks

The NHR, with a number of advanced design and safety features, can serve as a safe, clean and economic energy source for non-electric applications. The special design provisions adopted in the NHR for the coupling interfaces will insure that the heat grid or desalination plant is free of radioactivity. This has been demonstrated by the operating practice of the NHR-5. In particular, to keep the operating pressure in the intermediate circuit higher than that in the primary system and the heating grid is much significant for preventing radioactive coolant from leaking out and for maintaining high standard of water quality in the intermediate circuit.

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