# Characteristics, Development,

# and Applications of the NHR200-II

# Reactor in Non-Electric Energy

# Systems

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**Abstract**

As the latest small modular pressurized water reactor developed by the Institute of Nuclear and New Energy Technology (INET) of Tsinghua University, the NHR200-II maintains all the technical advantages of its predecessors (NHR5, NHR200-I), including integrated layout, full-power natural circulation, self-pressurization, intermediate loop isolation, and passive safety. The off-site emergency measures are technically unnecessary due to the elimination of large-scale radioactive release. Simplified auxiliary systems and component design requirements make NHR200-II operationally more straightforward, enhancing its economic viability. NHR200-II can meet various market demands, such as residential heating, industrial processing steam, cogeneration, seawater desalination, and centralized cooling. Currently, the industrial steam supply system is in the design phase, with the reactor having a power of 200MW and a primary circuit pressure of 8.0MPa, capable of providing superheated steam above 1.6MPa for industrial processes. With increasing demands for greenhouse gas emission reduction and air pollution control in China and globally, NHR200-II is poised for more emerging opportunities.

## INTRODUCTION

With the increasing non-electric application demand and safety requirements of nuclear energy, the Small Modular Reactors (SMRs), which can be deployed quickly and flexibly as demand arises, have been attracting more attentions from both technology vendors and investors in the world in recent years. As described in some of the International Atomic Energy Agency (IAEA) reports, there are more than 50 types of SMRs under different development stages from more than a dozen of countries, including China, Russia, and the USA [1]. As a big energy consumption country, China has been paying special attentions to SMRs in a bid to reduce greenhouse gas emissions and alleviate escalating air pollution.

Stemming from the 5MW low temperature nuclear heating test reactor (NHR5), which was designed and constructed by the Institute of Nuclear and New Energy Technology (INET) of Tsinghua University in the later 1980s, Nuclear Heating Reactor 200-II (NHR200-II) is characterized by several tested technologies, including integrated arrangement, full-power natural circulation, and passive safety systems. In addition, it has been improved in several aspects, including modularity and economy. Considering its technical maturity and inherent safety, the National Energy Administration of China has approved the feasibility study of the demonstration nuclear heating project based on NHR200-II in Jan. 2018. NHR200-II is hoped to be the first deployed SMR in northern China.

## THE ROADMAP OF NUCLEAR HEATING REACTOR IN CHINA

In 1983, the first civil nuclear heating test of China was successfully conducted on a swimming pool type reactor in Tsinghua University. As a new approach for district heating, it attracted wide attentions from both nuclear energy and heat-supply fields. However, in the following years, a consensus was reached that the vessel-type reactors, which can supply more than 120℃ hot water to heating network systems, is more suitable for big and medium cities in northern China, rather than pool-type reactors. In a bid to develop an inherently safe vessel-type reactor that can be deployed in a near distance of big cities, Tsinghua University has been focused on this area in the last three decades.

### Design and Construction of the 5MW Low Temperature Nuclear Heating Test Reactor

Under the support of the Ministry of Science and Technology, many key researches and characteristic designs of NHR5 had been completed, including integrated arrangement, full-power natural circulation, and internal hydraulic-drive control rod drive mechanism (CRDM). The construction of NHR5, which was located in the campus of INET, was begun in 1986 and was completed in 1989.

The NHR5 was used to supply heat for the whole campus of INET in three successive winter seasons, from 1990 to 1992, with the heating availability reaching up to 99%. The operation and tests showed outstanding performance of NHR5, including load following and inherent safety [2].

### Research and Promotion of the Nuclear Heating Reactor Demonstration Projects

Based on the design, construction and operation experiences of NHR5, INET developed a type of 200MW heating reactor, which later called NHR200-I, and all the necessary tests had been completed in the early 1990s. With the temperature of the water flowing out from the nuclear heating plant being 130℃, NHR200-I can highly match the existing heating networks of northern China cities.

As an alternative clean energy source, NHR200-I attracted the eyes of some local governments and entrepreneurs. Several demonstration projects had been suggested and promoted, some of which even have been approved in the following decade. Daqing, which is located in the cold northeast area of China, was one of the most active promoters. “Daqing 200MW Demonstration Nuclear Heating Plant” was approved by State Planning Commission in 1993. After strict and comprehensive nuclear safety reviews in the next three years, the National Nuclear Safety Administration of China licensed the construction permit of the plant. However, affected by the cancellation of Double-Track petroleum price policy, the price of so called unplanned petroleum that was used in Daqing district heating in those years plummeted sharply, which resulted in the disappearance of the economical driving force to substitute nuclear energy for oil. The Daqing project was unfortunately canceled. After that, some other investors also showed great interests in nuclear heating projects based on NHR200-I. The preliminary work of the nuclear heating project in Shenyang, another northeast city in China was approved by our central government in 2001. But the drastic changes of investor and the weakly economic competitiveness led to the termination of the project.

### Development of the Nuclear Heating Reactor Fleet

During the promotion process of NHR200-I, INET gradually realized that a pure residential nuclear heating project, which could only run in less than six months in a year, can hardly be economically competitive. A small size reactor should be multipurpose to enlarge its target markets and improve its economic competitiveness. Based on the survey of the industry steam market, INET started the research of NHR200-II, a new type of 200MW nuclear heating reactor that can supply the 201℃/1.6MPa steam which could satisfy quite a range of industry steam needs. This thus enables a variety of applications of NHR200-II, including process heat, district heating, seawater desalination, electricity generation in remote areas, and cogeneration.

Aiming the design changes led by parameter improvement, a series of key tests were planed and all of them had been completed before 2016. The inherent safety and passive safety remain in NHR200-II.

In addition, under the support of IAEA, a conceptual design of 10MW nuclear heating reactor was also completed, based on which a pre-project study of a desalination demonstration plant was jointly carried out by China and Morocco for Tan-Tan [3].

## THE GENERAL DESIGN OF NHR200-II

The main design parameters of NHR200-II are shown in Table I. In spite of the improvements of power and core temperature/pressure, the general design of NHR200-II is quite similar to NHR5, featured by integrated arrangement, full-power natural circulation, internal CRDM, and self-pressurization.

TABLE 1. Main design parameters of NHR200-II

|  |  |  |  |
| --- | --- | --- | --- |
| No. | Parameter Name | Unit | Value |
| 1 | Thermal Power | MW | 200 |
| 2 | Design life | Years | 60 |
| 3 | Primary Circuit Pressure | MPa | 8.0 |
| 4 | Core inlet/outlet Temperatures | ℃ | 232/280 |
| 5 | Intermediate Coolant Pressure | MPa | 8.8 |
| 6 | Steam pressure | MPa | 1.6 |
| 7 | Steam temperature | ℃ | 201.4 |
| 8 | Number of fuel assemblies | / | 208 |
| 9 | Fuel cycle | Months | 24 |

As shown in Figure 1, the reactor core, reactor internals, PHEs (Primary Heat Exchangers), and CRDMs are all arranged in the reactor vessel. The fuel assemblies are located in the lower space of the reactor vessel, and the PHEs are installed in the annular space enclosed by the reactor vessel and internals. A crafted gas space, filled by nitrogen and steam, is located in the top of the vessel to automatically pressurize the reactor circulate system.

The vessel is designed to be a dual pressure-containing structure. Even in an extreme accident that the reactor coolant leaks out through internal layer, it can be contained by the outer layer, practically eliminating the possibility of the loss of coolant through the vessel at the lower location.

As shown in Figure 2, the heat transfer system of NHR200-II incorporates the reactor coolant system, the Intermediate Coolant System (ICS), and the steam heat/power conversion system.

When flowing upward through the reactor core, the coolant is heated and flows upward into the riser, where it turns to horizontal flow. After flows through the primary heat exchangers, where it is cooled by the second-side intermediate loop water, the core coolant increases in density, naturally flows downward and returns to the core inlet.



*FIG. 1. NHR200-II Reactor Sketch.*



*FIG. 2. Sketch of NHR200-II Main Systems.*

The intermediate coolant system, which incorporates two isolated loops, with each of which can transfer 50% power, is driven by pumps. After flows out of the pumps, its water enters the second side of the PHEs, takes heat from the reactor coolant and flows into the first side of the steam generators, through which the water in the second side is heated and turns into saturated vapor to be supplied to various users.

Comparing to large nuclear power plants, NHR200-II is highly simplified and has only several limited auxiliary systems, including hydraulic control rod driving system, reactor coolant purifying and volume control system, overpressure protection system, and reactor component cooling water system.

## TECHNICAL FEATURES OF NHR200-II

### Reliable Cooling of Reactor Core

There several features that can prevent the loss of the reactor coolant, including elimination of large-size pipes in the RCS, the small-size pipes vessel nozzles being vertically much higher than the reactor core, and the dual pressure-containing structure of the vessel. In addition, the large coolant volume and low power density can also alleviate the coolant loss in accidents. According to our safety analysis, the reactor core can be covered by the coolant in all the design basis accidents and design extension conditions, allowing unlimited coping time in a design basis accident, or >168h in design extension condition without operator actions.

### Passive Safety systems

As shown in Figure 3, RHR (passive Residual Heat Removal system) includes two trains of independent decay heat removal loops. Each train contains of a set of PHEs (second side), a set of air coolers and associated pipes and valves. The core decay heat after reactor shutdown is finally dispersed into the atmosphere by natural circulation. There are no pumps in the system and all the valves would open on loss of power, assuring the decay heat removal in accidents.

In addition, the BIS (gravity Boron Injection System) is also a passive system and the boric acid can be injected into the core automatically by gravity in some design extension conditions in which the control rods hypothetically cannot be inserted, even though they can drop automatically into the core on loss of power or hydraulic force.

### Additional Physical Barrier to the Release of Radioactive Material

In addition to the physical barriers of the large nuclear plants in operation, an additional physical barrier, the ICS, is provided to prevent the release of radioactive material from the reactor coolant system to the steam power/heat conversion system. As the pressure of ICS, which is a high pressure closed system, is higher than that of RCS, the ICS water will leak into the RCS even if a PHE tube breaks, which means that in this kind of accidents the radioactive material will not enter the ICS, let alone steam system or heating networks.

### Off-Site Emergency Response Technically Unnecessary

The inherent safety and passive safety features enable the NHR200-II core coverage by coolant in all design basis accidents and design extension conditions, resulting in the elimination of large scale radioactive release. According to our analysis, the consequences of accidents can be limited in the plant area, with boundary less than 250 meters from the reactor. The accidents have no, or only minor radiological impacts off the site, and don’t necessitate any off-site intervention measures.

### System Design Simplification

As compared to large scale nuclear power plants, the design of NHR200-II is highly simplified, with high pressure injection systems, low pressure injection systems, containment spray systems all eliminated, resulting in a reduction in the number of components and simplification of operation. In addition, the inherent safety and passive safety design enables some systems and components to be designed as non-safety class items, including the reactor component cooling water system, the habitability system of main control room, and emergency diesel generator. The simplifications of system and component design and manufacturing, and plant operation, are helpful to improve the competitiveness of the reactor.



*FIG. 3. Sketch of NHR200-II passive safety systems.*

##  THE EMERGING OPPORTUNITIES FOR NHR200-II

The needs of air pollution control and green-house gas emission reduction are driving energy users seeking alternative resources in recent years, leading to new market opportunities for SMRs, including NHR200-II. Considering the tremendous energy demand and the need to reduce coal consumption in China, SMRs are hoping to occupy more energy markets in the coming decades, especially in the non-electric areas.

### Residential Heating

As described in “Cleaning Heating Plan in Winter Season of Northern China (2017-2021)”, up to the end of 2016, the building heating area in northern China is about 20.6 billion square meters, 83% of which is heated by coal-firing, and 400 million tons of standard coal are fired for heating each year. The needs to substitute coal with clean energy resources and new heating demands caused by urbanization lead to tremendous low-carbon heating requirements.

As an inherent reactor that can be deployed near large and medium-sized cities, a NHR200-II can satisfy the heating demand of about 4 million to 5 million square meters of buildings. As compared to the same scale coal-fired boilers, one reactor can reduce 385 thousand tons of CO2 emission each year.

### Industrial Processing Steam

The large number of factories in China creates huge processing steam market, a quite big part of which is low-parameter steam needs that can be covered by NHR200-II. According to “China Energy Statistical Yearbook”, the heat consumption market in 2017 was around 154.8 million tons of standard coal, more than 70% of which, about 109 tons, were used by industrial users [4]. As the steam delivery distance, less than 10km, is shorter than that of heating, distributed energy sources are more suitable. Required by regulators to reduce the coal consumption, the industrial users are seeking reliable and economically affordable energy. In this scenario, NHR200-II is more economically competitive than gas or electric boilers and is hoping to be deployed in industrial parks to satisfy the processing steam demands from nearby factories.

### Power Generation

Considering the design status and most economic analysis results, SMRs cannot yet economically compete with large nuclear power plants in power generation in the near future. As the power grid in China is relatively developed and most areas can be reached by other power generation vendors, we are not set it as a primary application of NHR200-II. Even so, NHR200-II is still a choice for power supply for remote areas. Additionally, in order to maintain the reactor power at a relative high level, a certain variable share of steam for power generation is also a recommend choice to cope with the seasonal change of residential heating demands and instability of processing heating needs, which is helpful to improve the economy of nuclear heating plants.

## CONCLUSIONS

As air pollution control and green-house gas emission reduction become rigid demands in China and around the world, reliable low-carbon alternative energy resources are attracting more attentions from both governments and investors. NHR200-II, a technically mature, inherently safe, and reliable SMR, which can satisfy various demands, including residential heating, industrial processing steam, cogeneration, seawater desalination, and centralized cooling, is facing emerging opportunities.

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