CN9201669

CNIC-00584
TSHUNE-0031

中国核科技报告
CHINA NUCLEAR SCIENCE & TECHNOLOGY REPORT

一种简单可行的低温核供热方案
——介绍两种池式低温供热堆

A SIMPLE AND FEASIBLE PROPOSAL FOR NUCLEAR DISTRICT HEATING
—— INTRODUCTION OF TWO KINDS OF POOL TYPE LOW - TEMPERATURE HEATING REACTORS

原子能出版社

中国核情报中心
China Nuclear Information Centre

田嘉夫；清华大学核能技术设计研究院副研究员，1960年毕业于清华大学工程物理系反应堆工程专业。

Tian Jiafu; Associate professor of the Institute of Nuclear Energy Technology, Tsinghua University. Graduated from the Department of Engineering physics of Tsinghua University in 1960, majoring in reactor engineering.

CNIC-00584
TSHUNE-0031

一种简单可行的核供热方案
——介绍两种池式低温供热堆

田嘉夫　杨　富　肖宏才
魏树柄　郭卫平　严育华

（清华大学核能技术设计研究院）

摘　要

介绍了功率为120MW，供应90℃热水的两种深水池式供热堆(DPR)。反应堆堆芯放置在一个大而深的水池底部，其活性区高为110cm，当量直径为174cm。其中DPR-1堆芯是自然循环冷却，而DPR-3是强迫循环冷却。由于反应堆在常压下运行，不会发生堆芯熔化事故，安全性好，可靠性高，技术上可立足国内。因此，这种深水池供热堆具有商用价值。

A SIMPLE AND FEASIBLE PROPOSAL FOR NUCLEAR DISTRICT HEATING

—— INTRODUCTION OF TWO KINDS OF POOL TYPE LOW - TEMPERATURE HEATING REACTORS

Tian Jiafu Yang Fu Xiao Hongcai
Wei Shubing Guo Weiping Yan Yuhua

(INSTITUTE OF NUCLEAR ENGINEERING TECHNOLOGY,
TSINGHUA UNIVERSITY)

ABSTRACT

The designs of two deep pool reactors (DPR) for district heating are presented. Each reactor has the ability to supply power of 120MW and hot water of 90℃. The reactor core is put on the bottom of a large and deep pool with activity zone of 110cm in height and 174cm in equivalent diameter. The core of DPR-1 is cooled by natural circulation and DPR-3 is cooled by forced circulation. This type of reactor is operated at normal pressure, and will be no accident of in-core melting. It has high reliability and good performance of safety and can be constructed by using domestic technology. The DPR could be used in commercial.

(A) DESIGN FOR DEEP POOL HEATING REACTOR (DPR-1)

INTRODUCTION

The temperature of the reactor core and the reactor systems has an important impact on the reactor design. A decrease in the temperature will make it possible to improve safety, reliability and economics of the reactor. There exists great differences between the parameters used in the coal-fired boilers and the one used in nuclear heating design.

According to the actual water temperature in the existing urban heating grids in North China, 85~90℃ inlet temperature of the heating grids will fully meet the base load requirements. The DPR heating plant, with low temperature and normal pressure features, the primary loop of which is flooded in a deep open pool (Fig. 1), has the following advantages:

(1) Loss of coolant in the reactor can be avoided absolutely and other accidents which have serious impacts on environment are impossible.

(2) Systems and facilities in heating plant can be simplified greatly.

(3) Experiences on the pool-type research reactor in China will make the nuclear heating plants to be constructed and put into operation with less investment in a shorter time.

Table 1 Main Parameters of the DPR-1 and the Heating Grid

item		parameter
reactor thermal power	(MW)	120
pool diameter	(m)	7
pool height	(m)	24
outlet temperature of core	(℃)	112.6
inlet temperature of core	(℃)	75
specified flow rate in primary loop	(t/h)	2744
No. of primary heat exchangers		4
power of primary heat exchanger	(MW)	30
outlet/inlet temperature in intermediate loop	(℃)	100/65
flow rate in intermediate loop	(t/h)	2919
No. of intermediate loop pumps (operating/standby)		4/2
specified outlet/inlet temperature in grid	(℃)	90/55
flow rate in grid	(t/h)	2890

The DPR heating plant consists of a big deep pool, an intermediate loop, heating grids, residual heat removal system, control system, waste water treatment, primary and intermediate water purification systems, ventilation system, radioactivity detective system, power supply system, and etc (Fig. 2). Main parameters of DPR-1 and the heating grid are listed in Table 1.

1 REACTOR CORE DESIGN

The conditions of DPR-1 design are:

(1) The rated reactor power is 120MW, and the refueling period is 150 full-power days.

(2) Average water temperature in core is 93.8℃ during full power. Moderator temperature coefficient and cavitation reactivity coefficient remain negative under all operation conditions.

(3) No boron solution will be added into the pool water.

(4) Single rods are used as control rods, meeting the requirement of the one-rod-group-failure principle, the other rods should be able to shut-down the reactor with subcritical degree of over 2.

(5) Under the condition of full power operation, flattening of radical power distribution requires: $p_{max}/p_{aver.} < 1.38$ (in X-Y plane).

(6) In equilibrium fuel cycle, average assembly discharge burnup is not less than 22GWD/tU.

(7) In the reactor design, low specific power and low line power density of fuel element are adopted. They will make the surface temperature of fuel element, central temperature, minimum ratio in firing have great safe margin compared with power reactors.

(8) On the outlet of the core, the water is in subcooled state and no voids appear, thus improve flow stability in the primary natural circulation loop.

(9) Natural circulation is used in the primary loop, which requires the ratio H/D of the core height to diameter in the core lower.

The reactor core design:

Based on the features of DPR, special arrangements are made: the height of the core activity zone is 110cm, the diameter of the activity zone is 174cm, and the fuel assemblies are kept in small sizes, which will be convenient in refueling and flattening of power distribution. The fuel element outer diameter is 10mm, zircaloy cladding thickness is 0.7mm, fuel pellet diameter is 8.43mm, and activity height is 110cm. The fuel elements are arrayed in 8×8 in assemblies. The 2×2 in the center are replaced by a guide thimble, which together with the three spacer grids form the framework of an assembly. A control rod or aluminum rod is in the guide thimble. The aluminum rod is always suspended at the end of a control rod, and thus well maintain flattening of power distribution in the assemblies. Each assembly has 60 fuel rods. The water gap between two assemblies is 0.8mm, and the distance between the centers of the two assemblies is 108mm. The pitch between the fuel elements is 13.4mm, the outer diameter of the guide thimble is 29mm, and its inner diameter is 26mm (water/uranivm in volume is 1.90).

Reactor core structure:

The core consists of 205 fuel assemblies, or totally 12,300 fuel rods. The total weight of uranium oxide is 7.715t.

Refueling will be made each year, using new assemblies with uranium-235 enrichment 3%. The 101 control rods are constructed by stainless steel thimbles with B_4C in the center cladded. The outer diameter is 24mm. An alternative control system consists of 89 control rods.

The open pool arrangement is used in the reactor, and the reactor core is located at the bottom of the pool, where the static pressure is 0.301MPa (see Table 2).

Table 2 Major Parameters of the Reactor Core

item		parameter
thermal power	(MW)	120
power density	(kW/L)	45.6
activity height	(cm)	110
equivalence diameter	(cm)	174
No. of fuel assemblies		205
total weight of UO_2	(t)	7.715
water-to-uranium volume ratio		1.902
No. of fuel rods in each assembly		60
fuel rod arrangement in assembly		8×8
fuel assembly dimension, cm×cm		10.8×10.8
pitch between rods	(mm)	13.4
average discharge burnup	(MWD/tU)	22,000
average line power density	(W/cm)	88.69
static pressure	(MPa)	0.301
normal inlet/outlet temperature	(℃)	75/112.6
maxmum central temperature	(℃)	800
DNBR		>2.5

2 PRIMARY LOOP OF REACTOR

All components of the primary loop are installed in the open pool of the DPR, including the reactor core, the riser, and the primary heat exchangers. Average height difference between the reactor core and the primary heat exchangers is 16.4m. The driving pressure of the primary natural circulatvon is 4165 Pa.

The primary loop components are usually made of aluminum alloy, which can be fabricated in high quality, and has perfect mechanical and anti-corrosion properties in the temperature range of 50～120℃. Aluminum alloy is also quite inexpensive compared with other metals and contributes to lower the investment.

The only plant-specific equipment is the primary heat exchangers, and has the following proprties:

(1) Considering natural circulation requirements, and to avoid boiling the inlets of the exchangers are located at 9m below the water surface and the oulets near the surface. The total flow length is about 8m.

(2) Single-phase natural circulation requires a low flow resistence in the exchangers, favorably limited in the range of 980～1470Pa.

(3) In order to increase supply water temperature, the main exchangers should be operated at a low temperature difference between the primary and secondary loops.

Through the analysis of the three features about, it can be concluded that, a long flow length in the exchanger will cause difficulties in maintaining low flow resistance; and the low flow resistance and low temperature difference result in an increase of the heat exchange area. The impact is compensated by intensified heat transfer to improve heat conductivity under the conditions of low temperature, low pressure and low flow velocity in the design of primary heat exchangers, so the costs of the primary heat exchangers are kept relatively low.

(B) A NEW DESIGN FOR DEEP POOL HEATING REACTOR DPR-3

In the previous design, natural circulation is established in the primary loop to remove heat from the core. The natural circulation requires all the components in the primary loop to be installed in the open pool; and special heat exchangers should be designed and tested to meet the requirements for natural circulation. So some money used in pre-research as well as some time will be needed. But a new design for DPR —— DPR-3 Will have none of these problems. The main parameters in DPR-3 design are similar to that of DPR-1 (see Table 3) But the DPR-3 heating reactor is based on the practical technology and apparatus, So it can be used directly in project construction.

Owing to the high flow resistance in the exchangers, DPR-3 establishes forced circulation in the primary loop, with the heat exchangers and pumps installed outside the pool. Still large amounts of water remain under both the level of the penetrations in the pool wall and the level of the pumps and heat exchangers, thus that means a long "grace period" and secure high inherent safety of the reactor.

The specifications and parameters of DPR-3 are similar to those of DPR-1, the DPR-3 is more feasible to be put into construction than the former one due to using conventional technology and equipment.

The core of DPR-3 is also located at the lower part of the pool. Hot water out of the core goes along the hot water riser, then flows outside the pool to cool through the plate heat exchangers and returns to the pool through the stainless pumps. Such concept of forced circulation loop, avoids the problems occured in DPR-1, in which ripe technology and device are used.

Table 3 Major Parameters of DPR-3

item		parameter
thermal power	(MW)	120
inner diameter of pool	(m)	7
depth of pool water	(m)	24
inlet temperature of core	(℃)	80
outlet temperature of core	(℃)	110
specified flow rate of core	(t/h)	3420
No. of primary heat exchangers		8
power for each heat exchanger	(MW)	15
inlet/outlet temperature of intermediate loop	(℃)	70/100
flow rate in intermediate loop	(t/h)	3428
No. of pumps in intermediate loop (operating/alternative)		4/2
flow rate in heat grids	(t/h)	3434
inlet/outlet temperature in heat grids	(℃)	90/60

At normal operating condition, the circulation of cool water through core is driven by pump, but the natural circulation can be created by the gas lock when pump is failure. In case the pump borken down, the control rods drops and the gas lock located at the riser above the core in the pool opens automatically. The residual heat is removed by both pool water and the residual heat exchanger in the pool. Compared with DPR-1, DPR-3 has the same safety feature. Owing to the forced circulation induced, the flow velocity in the main heat exchanger is raised with increased efficiency and reduced heat exchange area. Although, the investment on heat exchanger goes down, there is increasement of pumps, valves, and pump rooms cost. The total investments of DPR-1 and DPR-3 are similar.

Although there is more electric power consumption on pump operation, DPR-3 has a great convenience in heat exchanger maintenance, and has safety in part loaded operation when some pumps are broken down. These properties are important for the first nuclear heating demonstration project. For the reliability of district heating has a direct social influence on civilian life, it is necessary to have a higher ensurance.

In our opinion, the first DPR to be built should be DPR-3 with its single power scale of 120MW or more than 200MW. The building of DPR-3 is helpful to the construction of DPR-1.

These two kinds of heating reactors have the same core structure, control pattern, fuel loading and equipment maintenance methods, and similar inlet and outlet core temperature. They are both suitable for the user whose supply water temperature of heating grids is below 100℃. Especially for most North cities and industrial areas. Used with other heating sources (such as peak load boiler), the supply water temperature in the grids might reach 120℃ and this is the most economical way for nuclear district heating.

The common features of DPR-1 and DPR-3 is excellent inherent safety, simple structure and relatively lower investment. Because their working temperature is below 110℃ in the reactor core, most structural materials in the pool are aluminum alloy.

With aluminum used, there are many convenients in water property control, water activity, checking and retiring of equipment and the possibility to study aluminum cladded fuel rod which will have great benifit for the technical and economical property of the low-temperature heating reactor.

The two kinds of the reactor can utilize both the neutron and γ from the core easily and are favorable for comprehensive utilization of nuclear energy.

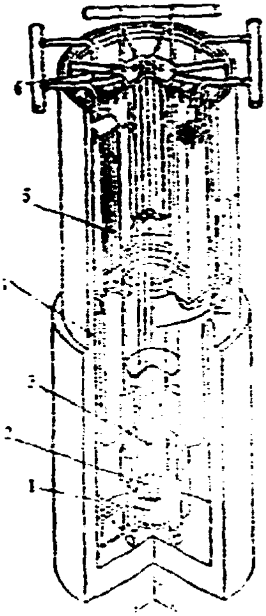

Fig. 1 Low-Temperature Pool-Type Heating Reactor for Comprehensive Utilization of Nuclear Energy

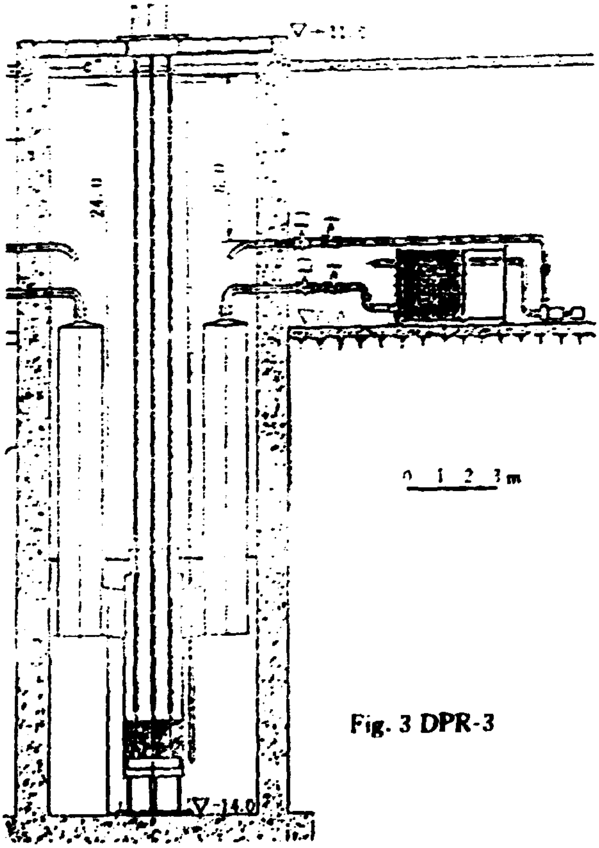

Fig. 3 DPR-3

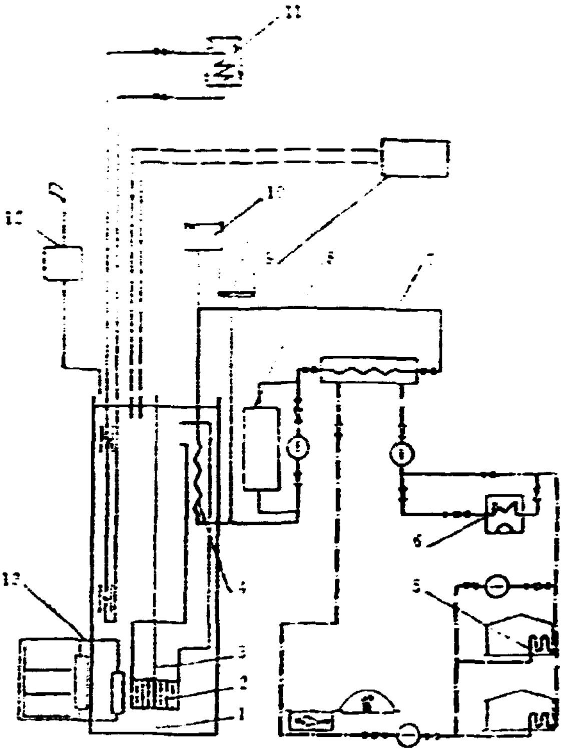

Fig. 2 Systems Layout of the Heating Reactor

1 water pool
2 reactor core
3 control rod and driver
4 primary loop heat exchangers
5 heat grid
6 peakload boiler
7 intermediate loop

8 waste water treatment of intermediate loop
9 waste water treatment of primary loop
10 water tank
11 residual heat removal
12 special ventilation system
13 irradiation loop

一种简单可行的低温核供热方案
——介绍两种池式低温供热堆
原子能出版社出版
（北京2108信箱）
中国核情报中心排版
北京市海淀区三环快速印刷厂印刷

☆

开本787×1092 1/16 ·印张1/2·字数7千字
1992年2月北京第一版·1992年2月北京第一次印刷
ISBN 7-5022-0599-3
TL·354

CHINA NUCLEAR SCIENCE & TECHNOLOGY REPORT

P.O.Box 2103
Beijing, China

ISBN 7-5022-0599-3
TL · 354

China Nuclear Information Centre