THE PRESENT STATUS AND THE PROSPECT OF CHINA RESEARCH REACTORS

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ABSTRACT

A total of 100 reactor operation years' experience of research reactors has now been obtained in China. The type and principal parameters of China research reactors and their operating status are briefly introduced in this paper.

China research reactors have been playing an important role on nuclear power and nuclear weapon development, industral and agricultural production, medicine, basic and applied science reseach and enviromental protection, etc.

The utilization scale, benefit and achievement will be given.

There is a good safety record in these reactors operation. A general safety review is discussed. The important incidents and accidents happened during a hundred reactor operating years are described and analysed.

China has got the capability to develop any type of research reactor.

The prospective projects are briefly introduced too.

THE PRESENT STATUS AND THE PROSPECT OF CHINA RESEARCH REACTORS

1. China research reactor's type, main parameters and operation situation

China research reactor has an operation experience of over 100 reactor years. Its type and main parameters are listed in Table I and its operation situation is introduced as follows.

1.1. HWRR (1) (2)

HWRR was China's earliest research reactor imported from USSR. It took 2%U-235 metal uranium as fuel, heavy water as moderator and coolant, graphite as reflector. Its nominal power was 7MW, strengthened power was 10 MW, and the maximum thermal flux was 1.2 x 10^{14} n/cm^2.s.

HWRR's historical development might be devided roughly into three periods.

The first period was from 1958 to 1978 with assimilating, digesting, improving and safe operating as its main task. In this period, the Chinese technicians made improvement in every system of the reactor and in reactor character. The reactor's utilization was enlarged and meanwhile a great number of reactor engineering scientists and technicians were trained.

The second period was from 1979 to 1982 with the aim of reactor's reconstruction. In the first phase of the reconstruction project, stress was laid on core replacement and heavy water system reform, and these works was completed on June of 1980. The second phase was implimented from 1980 to 1982, mainly to renew the measuring instruments and introduce the process control computer. The data measured after reconstruction show that the reactor's technical index have totally reached the reconstruction design requirement, the major characteristic parameters are showed in Table I.

After 1982 began the third period of the reactor's further application. During this period, HWRR completed fuel assembly test for Qinshan Nuclear Plant, let NTD silicon be produced commercially and cold neutron source be installed and put into operation. Now thirty years have gone, but HWRR still plays its important role in the fields of China's nuclear technology. At present HWRR works 10 to 20 days each month in the light of needs.

1.2. SPR

There are three swimming pool reactors in China now. SPR-IAE (3) is a reactor put into operation on Oct. of 1964, with the construction aim of testing fuel and materials. The reactor has been improved greatly during the past 23 years. Its rated power is gradually increased to 3.5MW and it gets various accessory facilities. The reactor then becomes a multipurpose reactor that works on reactor physics experiment, neutron radiograph, radiosotopes production and NTD silicon irradiation apart from its testing work. Now the reactor works about 10 days each month.

SPR-QHU Core No.1's original design power is 2 MW. At present natural convection cooling is applied and its working power is only 50KW. It is mainly for making shielding material experiment and other irradiation test. In 1975, a 2.8MW core No.2 was installed opposite the core NO.1 for comprehensive utilization. The two cores share one water pool. In 1983 a low temperature heating experiment was made on core No.2 and this provides data and experiences for developing the low temperature heating reactor.

SPR(4)-IPC is China's third swimming pool reactor. Apart from completing special tasks assigned by the state, it also works on monocrystal silicon doping, neutron activation analysis, material irradiation test, neutron radiograph, etc. And remarkable success is specially achieved in neutron radiograph's practical application.

1.3 HFETR (5)(6)

HFETR is mainly used in the irradiation character research of power reactor's fuel and material and the production of radioisotopes. High power operation began in 1980, and a total of 16 loadings had been operated by the end of 1987, 309 fuel assemblies and 40 follower assemblies were loaded. The accumulative power is 20560MWD. From first to sixteenth loading the fuel assemblies for each loading were increased from 25 assemblies to 57 assemblies, power from 40MW to 90MW. Since the refueling pattern of zoned replacement is applied, the unloading element' average burn-up is 42%.

In HFETR's main building, there are places for installing various experiment facilities. It is possible for constructing 9 test loops such as water cooling, gas cooling and sodium cooling test loop. But due to some reasons there is only a high temperature and pressure water loop under construction by now. The reactor is not fully utilized and operated only 8 to 10 days each month for material irradiation reaearch and irradiation products.

1.4. MNSR (7)(8)

MNSR is a safe, compact, economic and efficient tool which is applicable for neutron activation analysis, radioisotope production, education and other purposed. It is specially suitable for use of hospital, university and research institutes. In 1984, a prototype reactor was constructed and several years operation shows the reactor has reached its design parameters with a good properites and safety. In recent years, two commercial reactors were constructed in Shenzhen and Shandong in succession.

2. China research reactor's application

China research reactor has played an important role in developing nuclear power and weapon, industrial and agricultural porduction, medicine science, basic and applied science and research.

2.1. Plutonium reactor and power reactor's fuel element test.

The fuel element test are mainly made on HWRR and SPR-IAE. Since 1965, SPR-IAE has built 4 sets of high temperature and pressure, middle temperature and pressure test loops in core, and a total of ten types' home-made plutonium reactor and power reactor fuel elements have been tested.

These tests have made important contribution to the increase of prototype reactor power and fuel burn-up index, the element lifetime prolongation, the optimum manufacture process selection, and the increase of the element qualification rate. At the same time, research has also been made on UO_2 pellet's temperature and thermal conductivity measurement. All elements tested are short rod because of size limitation of SPR core.

During the year of 1966 to 1970, a high temperature and pressure test loop was installed in HWRR's central thimble to test China's first nuclear submarine element. It had two loading and gained the expected results. It provided reliable basis for the elements production, and we have tested several kinds of metallic uranium elements in the reactor.

After the reconstruction, a new and high temperature and pressure test loop(9) was set up in HWRR's central thimble (ϕ 120mm) to test the fuel element of Qinshan Nuclear Plant. The test loop parameters are 15.5Mpa, 320°C. The assembly U -235's enrichment is 10%. The assemblies structure is 3X3-2. Its maximum power is 290KW and the maximum heat flux 1.45 $X10^6$ Kcal/m²h The unloading assemblies' mean burn-up is 25,000MWD/T. The test work has made contributions to the elements production of the Qinshan Nuclear Plant.

HFETR also fulfilled some fuel single rod's test inserted directly in the core, such as the UO_2 fuel rod containing burnable poison and the ThO_2 fuel samples. A new test loop is under the construction.

2.2. Research on irradiated character of the reactor's structure material.

Research works are mainly done in reactor HFETR and SPR, for their neutron energy spectra is harder and their fast neutron flux is higher.

The pressure vessel steel, such as 645 steel, 728 steel, LT21, LT24 aluminium alloy, Al-Li alloy, Zr-Al alloy, cables and paintings etc, were irradiated in reactor SPR-IAE. The alloy material's moving water corrosion test was developed on strong radiation fields.

Material in core irradiation and temperature control irradiation are carried on reactor HFETR. The material being researched are A 508-3 steel, S271 steel, fast reactor steel, B-10 steel, permeated boron stainless steel, Zr-4 etc, and the detective devices and elements such as transducer, new type thermo-couple and Pt detector.

2.3. The production of radioisotops

The man-made radioisotopes's research started in 1958 Along with the development of the research reactor, China's radioisotopes research and production has a considerable scale. There are more than 800 kinds of products in the country, and 150,000 pieces of products are delivered each year to over 1500 consumers. Most of the radioisotope products are produced by HWRR. The main products are I-131, I-125, Au-198, P-32, Ba-131, C-14, I-192 and Po-210 etc. The radioisotope products produced by HWRR meets the 70% of domestic demand.

SPR-IAE's main products are M0-99-Tc-99m, Cr-51, and non carrier P-32 using the characteristic of its low temperature of moderator.

HFETR mainly takes its high excess reactivity as advantage to produce medical, industrial and agricultural intensive cobalt source, Ir-192--the source of defect detecter, high specific intensity C-14, Sn-113-In-113M, M0-99-Tc-99m isotope generator and transplutonium.

2.4. Neutron transmutation doping in monocrystal silicon. (10)

China started to develop NTD technology since 1980. Now five research reactors are taking monocrystal silicon irradiation. The irradiation ability per year is over 40 ppb-tons, its actural irradiation quantity is 10 tons. The doping scope is from 1000Ω.cm-10Ω.cm, the doping uniformity, accuracy and annealing technolgy have reached international level. NTD technology have been basically adopted for The China-made monocrystal silicon used as producing power device, hence the apparent improvement of the device quality have been realized.

2.5. Neutron activation analysis

All the research reactors do neutron activation analysis work. HWRR, MNSR-IAE, SPR-QHU, these three reactors undertake a bigger work quantity. The analysis sample quantity each year are 10,000 to 3,0000 most of them are environmental samples, superpure material, mineral samples, and biological samples. They can analysis over 70 kinds of chemical elements with a sensibility from several hundred ppm to grade ppb. meanwhile, the neutron activation analysis has become one of the main analysis methods for quantification of standard reference materials.

12.6. Neutron scattering and neutron diffracting experiments (11)

Neutron scattering research is carried on HWRR's horizontal experimental channels. In recent years, cold source with 0.4 litres, cold guide tube with 30 meter long and a small angle scattering spectrometer are installed in HWRR NO.4 horizontal experimental channel by China-France cooperation. At cold guide tubeexit, the cold neutron beam intensity can reach to 10^8 $n/cm^2 sec$ with a better cold neutron gain. This set of equipment can take into use at the end of this year.

4-circle diffractometers, triple-axis spectrometer and flying time spectrometer are installed on the other horizontal experimental channels mainly for the research work of crystal and magnetic structure, phonon dispersion study, phonons in metal hydrides and superconductors diffusion process, etc.

Besides the above application, we adopt the technology of neutron radiograph, irradiation seed breeding and nuclear pore filter film etc. A gamma irradiation device with a diameter of 180mm using the unloaded element has been installed in the storage pool of the HFETR, and gamma field intensity can reach to 2×10^7 R/h. A successful irradiation-crosslinking treatment to 30 tons of polythene has been done in the device.

3. Commentary on the safe operation of China research reactors (12)

3.1. The brief information of safe operation of China research reactor.

China research reactor has an operation experience of over 100 reactor years with a good record for safety operation. The collective dose equivalent per MWY of the reactor's operating staff can be seen in Table II. After HWRR reconstruction, since we substitute metal uranium with UO_2 for fuel and replace the bead welding cobalt alloy to the sputter coating with non-cobalt wear-resistant alloy on shaft sleeve and thrust bearing disk of the heavy water pump, since we have improved the reactor operation process, collected sufficient experience in reactor's maintinance work and strengthened the management work of the reactor hall and chamber, the value of collective dose equivalent of releasing unit energy is apparently lower than that before the reconstruction. Compared with such value of reactors out side China, we do believe that China research reactor is in line with them.

The intensity of radioactivity from HWRR to the environment can be seen in Table III. After the reconstruction, since we have added HEPA filter and deiodine filter in the ventilation system of the reactor chamber, the discharging amount of radioactive iodine and aerosol to the enviornment have been dropped apparently. Since the discharging amount of radioactivity from the other China research reactors are far less than that of HWRR, we will not give the exact value in this paper. The amount of radioactivity to the environment from the China research reactors are less than the permissible limitation, it never cause any sensible influence to inhabitants around and we have not found any case of radioactive sufferer from the reactor operators whom we give a thorough health checking regularly.

3.2. The incidents and accidents of China research reactors happened in the period of 1958-1988 and analysis.

From Table IV we can see the main incidents and accidents of China research reactors happened within the past three decades. For each incident or accident, we give a brief status, causes and radiological consequences. There are two common characters for all these incidents and accidents listed in Table IV.

a. The main causes for the incidents (accidents) or extending radiological consequence are due to the misjudgement or maloperation. Over 70% of incidents or accidents listed in Table IV are man induced events.

b. Most of the incidents or accidents which bring about radiological consequence, are due to the failure of the test loop, isotopic target, experimental source and sample etc. Incident or accident caused by the defect or failure of the equipment of the reactor is rare.

We believe that the most effective improvement to the safety operation of research reactor is to train a qualified operating staff, improve their ability of coping with emergency and strengthen the management to the experimental items of the research reactor including a strict safety review to every device and sample which is going to be sent into the reactor.

3.3. The pubilication and execution of The Safety Regulation to China Research Reactor.

In Oct. 1986, the State Council of the People's Republic of China issued "The PRC Civil Nuclear Facilities Regulatory Supervision Rule" and the Nuclear Safety Brureau gave a detailed and definite interpretation to the rule for its execution. China research reactors are under the direct jurisdiction of the above two documentations.

In Aug. 1988, the Nuclear Safety Bureau of the People's Republic of China issued "Code for Safe Operation of Research Reactors and Critical Assemblies". The other safety guides for the China research reactor are being prepared and discussed and three of them are going to issue in the near future.

Now all the research reactors and the critical devices in China are under the supervision of the Nuclear Safety Bureau of the People's Republic of China. Safety analysis report for HWRR, HFETR and SPR were submitted, and the adding safety facilities in order to improve the safety have almost completed according to the schedule. The Nuclear Safety Bureau will issue operation licences for them. Concerning MNSR, pulse reactor and low temperature heating reactor which are under the construction, they will accept the safety review from the Nuclear Safety Bureau and are waiting for approvement of fuel loading and operation licences.

The publication and execution of The Safety Regulation to China Research Reactors will further raise the safety operation level of the research reactor.

4. The developing prospect of China Research Reactors

4.1. Full utilization and reformation to the completed reactors in China

From our statement in Chapter 1 we can see that the utilization efficiency of China research reactor are not so ideal, the operating time for each reactor is only 10 days per month in average reflects a rather low operating efficciency and the utilization efficiency of experimental thimbles is expecting for further raising. on one hand, we should further exploit application items of the reaearch reactors and attract more users, on the other hand, we must strengthen the reformation of our research reactors, add the auxilary facilities so as to enlarge the capability of comprehensive utilization and decrease the using cost.

We are planning to build MNSR in the coastal area for activation analysis, education and training.

In Southwest China Reactor Research Center, we will build a low power reactor using the unloaded element from HFETR. The reactor will load 32 assemblies of HFETR unloading element of forty percent of burn-up. The reactor power is 5MW. The generating energy for each loading is 340 MWD and element burn-up of final stage is 45%.

This low power reactor can be used for the irradiation of monocrystal silicon and production of radioisotopes like fission Mo-Tc. The reactor will be operating in 1990 according to the schedule and it will take a full use of HFETR element and realize the aim of economization, tapping the potentialities and low irradiation cost.

4.2. The development of new type reactors

a. Pulse reactor (13)

To develop the reactor with possessed inherent safety, A prototype pulse reactor designed by IRERD is under the construction, this pulse reactor will be similar to TRIGA-II and the main parameters will be as follows.

1. Reactor core

Diameter: 540mm Height: 390mm

Fuel loading: 3.45kg U-235

Core total life time: 150MWD

2. Fuel element

Diameter: 37.2mm Ingredient: UZrH1.6

Concentrition of U-235: 20%

Uranium content: 8.5Wt%

3. Stationary condition

Rated power: 1000KW $\bar{\Phi}$th: 1.4×10^{13} n/cm^2.s $\bar{\Phi}$f: 2.4×10^{13} n/cm^2.s

Mean power dencity: 15.8W/cm3

Max. power non-uniform coefficient: 2.31

4. Pulse condition

Max. pulse reactivity add: 3$

Pulse peak power : 4900MW

Pulse peak flux: 6×10^{16} n/cm^2.s

Pulse half-width: 7ms

Generate energy per pulse: 38.8MWS

We are expecting to complete the prototype reactor in the coming year and carry out the verifying experiments of physics, thermodynamics, control and nuclear measurement. under the stationary and pulse conditions. After the completion of safety analysis and optimizing design, we are going to build a UHZrPR-A purlse demonstrative reactor and realize the commercial operation. Further exploitation to the low temperature heating reactor UHZrPR-B will be done by adopting the technology and experience from UHZr{R-A reactor.

b. Low temperature heating reactor (14)

We might see the developing future of low temperature heating reactor in the areas in China where are lack of energy sources. Engineers and technical staff in the Nuclear Energy Institute of Qinhua University are installing and commissioning a low temperature heating prototype reactor. Prof. Lui Yingzhong and his Colleague have obtained the inventive certificate from the patent Office of the People's Republic of China for the deep water type heating reactor.

With its own qualified design units and construction teams, china has collected a considerable experience in developing, making and operating the research reactor, and is able to design and build any type of research reactor and its fuel element. We are willing to offer the Chinese technology and construction experience in the nuclear fields and promote the international cooperation.

Table 1 Type and main parameters of China research reactors

Reactor Name	Critical Date	Reactor Address	Reactor type. fuel type. ^{235}U Concentration. moderator. Coolant. Reflector.	Power MW	The max ϕ_{th} n/cm^2 sec.
HWRR	1958	IAE Beijing	Heavy Water Uo_2, 3% ^{235}U, D_2o, D_2o, graphite.	15	2.4×10^{14}
SPR --IAE	1964	IAE Beijing	Swimming Pool Uo_2, 87% wt Uo_2 + 13% wt Mg, 10% ^{235}U H_2o, H_2o, Be + C	3.5	4.0×10^{13}
SPR --QHU	1964	INET Qinghua University	Swimming Pool Uo_2. 87% wt Uo_2 + 13% wt Mg, 10% ^{235}U H_2o, H_2o, C.	2.8	3.5×10^{13}
SPR --IPC	1979	Southwest IPC	Swimming Pool Uo_2, 87%wt Uo_2 + 13%wt Mg, 10% ^{235}U H_2o, H_2o, C.	2.0	3.0×10^{13}
HFETR	1979	Southwest IRERD	Tank UAL_4, 25.4%wt U, 90% ^{235}U H_2o, H_2o, Be + Al	125	6.2×10^{14}
MNSR --IAE	1984	IEA Beijing	Tank in Pool UAL_4, 26.7%wt U, 90% ^{235}U, H_2o, H_2o, Be	27KW	1×10^{12}
MNSR --SZ	1988	Shenzhen University	Tank in Pool UAL_4, 26.7%wt U, 90% ^{235}U, H_2o, H_2o, Be	27KW	1×10^{12}
MNSR --SD	1989	Shan dong Geology Bureau	Tank in Pool UAL_4, 26.7%wt U, 90% ^{235}U, H_2o, H_2o, Be	27KW	1×10^{12}

Table 2. Collective dose equivalent of pesonnel per MWY (Person - Sv)

HWRR Before reconstruction	HWRR After reconstruction	HFETR	SPR - IAE. QHU. IPC
34.6×10^{-2}	7.9×10^{-2}	4.6×10^{-2}	$(1 -- 4) \times 10^{-2}$

Table 3. HWRR radioactivity released to environment (Ci/Y)

	Through exhaust stack				Through drain of effluent	
	^{41}Ar	^{3}H	^{131}I, ^{125}I	Aerosol totol β	^{3}H	totol β
Before reconstruction	2700	40	0.1	0.038	3	
After reconstruction	3980	54	0.02	0.001	1	3×10^{-3}*

* Integral raleased quantity of IAE.

Table 4. The main incidents /accidents occured in 1958 - 1988

Reactor	Date	Status	Cause	Radiological consequences
HWRR -1	1958 -1986	Heavy water leakage from reactor system to processing rooms, 9 times.	Cracking of isolation shell of Heavy water pump and instrument valves; welding seam crack of instrument connecting pipes.	Release ^3H of 0.05 - 40 Ci.
HWRR -2	1959 -1987	Period over short, 5 times.	Insufficient valuation for experiment reactivity and maloperation.	/
HWRR -3	1961 -1987	Breakdown of process tube, 10 times.	Mechanical damage from flow vibration.	/
HWRR -4	1970.9	Fall of fuel element on the bottom of the reactor vessel.	Break down at the bottom of the process tube during handling.	Integral dose equivalent: -3 person. rem
HWRR -5	1969 -1977	Failure of fuel elements, 9 times. 1 in which meltdown.	Malfunction of non-destruction test in production, maloperation.	2 months for disposal, integral dose equivalent: -12 person. rem
HWRR -6	1962	Blockage of one safety rod.	Rust of iron cable.	/
HWRR -7	1981	Fall of regulation rod.	Break down of cable from mechanical wear.	/
HWRR -8	1974.7	Heavy water leakage to heat exchanger shell cavity.	Cracking at welding seam of exchanger vessel.	/

Reactor	Date	Status	Cause	Radiological consequences
HWRR -9	1985.12	Heavy water leakage from heat exchanger to secondary water.	Welding cracking of tube end at tube plate.	7 days for disposal
HWRR -10	1964.8	Spurt of ThO_2 powder sample.	Burst of glass capsule from radiation.	Release ThO_2 of 1 mci to Reactor cabinet.
HWRR -11	1971.12	Leakage of ammoniun dichromate.	Burst of irradiation capsule from Radiation decomposition.	5 persons are contaminated.
HWRR -12	1973.9	Leakage of RI ^{131}I.	Design defect of irradiation capsule and malfunction.	Release ^{131}I of 3.4Ci.
HWRR -13	1981 -1986	Leakage of sample I.	Failure of irradiation capsule.	Release ^{131}I of 0.05 - 30 mci.
HWRR -14	1975.1	Leakage of sample Hg to the reactor vessel and heavy water loop.	Burst of quartz capsule, damage of irradiation facility and experimental channel from corrosion mercuride.	Release ^{203}Hg of 53mci to atmosphere.
HWRR -15	1966.12	Escape of radioactive gas from test loop.	Failure of test fuel element and breakdown of rubber sampling tube during sampling of water.	Release ^{133}Xe of 45 Ci to atmosphare.

Reactor	Date	Status	Cause	Radiological consequences
HWRR -16	1977.5	Meltdown of test fuel element.	Febrication defects of test loop facitities and transgressing the operating instruction.	Release ^{133}Xe of 1650 Ci and ^{131}I of 20 mci to atmosphere.
HWRR -17	1964.3	PuO_2 micro-particles spilliage from sample.	Maloperation of experimental personnel.	Contaminated area: 1500 M^2. α radioactivity : 1.1 mci.
HWRR -18	1964.4	Radium microparticles spilliage from sample.	Transgressing the operating instruction.	Contaminated area: 100 m^2 α radioactivity intensity: 1 mci.
HWRR -19	1972	Abnormal increase of radiation in reaction cabinet.	Erroneous replacement of RI cobalt target in the reactor temporary keeping thimble.	Collective dose equivalent: 18 person rem.
HWRR -20	1980.7	Spread of Heavy water with ^3H.	Breakdown of rubber filling tube during critical experiment.	Release ^3H of 1 Ci to atmosphere.
SPR-IAE -21	1965.4	Shaft break down of test loop pump.	Defect of material	/
SPR-IAE -22	1967.7	Burst of test loop heating section.	Maloperation.	/
SPR-IAE -23	1969.6	Burn down of pump packing in secondary loop.	Maloperation.	/
SPR-IAE -24	1969.10	Meltdown of test fuel element.	Test loop lose flow	Release inert gas of hundreds Ci, Aerosol of 1.5 mci to atmosphere.

Reactor	Date	Status	Cause	Radiological consequences
SPR-IAE -25	1970.10	Abnomal oscillation of reactor power.	Boiling of pool water penetrated into the central experimental channel.	/
SPR-IAE -26	1971.	Heat isolation tube cracking of test loop.	Corrosion of aluminium alloy with defect.	/
SPR-IAE -27	1974 -1980.	Leakage of RI target (P,Mo_2O_3); burst of NAA sample capsule.	Fabrication defect of irradiation capsule.	Reactor hall contaminated.
SPR-IAE -28	1981.	Reactor power rising period shorter than 12 sec.	Abnormal withdrawal of Cd covered sample.	/
HFETR -29	1981.	Interruption of two independent outside electrical power supply.	Sounder stroke on large area.	/
HFETR -30	1983.	Overpower operation.	Maladjusted power setting device.	/

REFERENCES

(1) . Zhong Yan
HEAVY WATER RESEARCH REACTOR
Atomic Energy Publisher
Beijing (1989)

(2) . MA FUBANG & LIN CHENGGE etc.
RESEARCH ON HWRR RECONSTRUCTION DESIGN
Chinese Journal of Nuclear Science &
Engineering
Vol.1 NO.1 P20-P26 (1981)

(3) . WANG LIUQUI
REACTOR OPERATION MANAGEMENT & TECHNICAL
INNOVATION OF SPR-IEA
Japan-China Symposium on Research & Test
Reactor
OP-8, Feb.29--Mar.2, 1988

(4) . MA ZHENZE
A NEUTRON RADIOGRAPHIC FACILITY ON A RESEARCH
REACTOR & SOME RESULTS OBTAINED IN NDT
Proceedings of the World Secondary Neutron
Radiography Coference
Paris (1986)

(5) . XU CHUANXIAO & ZHOU YONGMAO etc.
THE HIGH FLUX ENGINEERING TEST REACTOR
Nuclear Power Engineering
Vol.2 NO.3 P1--P15 (1981)

(6) . LU GUANGQUAN

ECONOMIC ANALYSIS & COMPREHENSIVE UTILIZATION OF HFETR
Nuclear Power Engineering
VOL.10 NO.2 P1--P5 (1989)

(7). ZHOU YONGMAO
THE MNSR REACTOR
Proceeding for Study Tour on RRU, IAEA (1986)

(8). GAO JIJIN & FU JINSHU
THE MNSR REACTOR & APPLICATION
Japan-China Symposium on Research & Test Reactor
GR-11, Feb.29--Mar.2, 1988

(9). HAN YIQIA & ZHANG SHUCHENG
PROVING TEST OF FUEL ASSEMBLY FOR QINSHAN NUCLEAR POWER PLANT
Japan-China Symposium on Research & Test Reactor
UT-03, Feb.29--Mar.2, 1988

(10). CAO YIZHENG & GAO JIJIN
THE DEVELOPMENT OF NTD TECHNOLOGY IN IAE
Proceedings of the Fourth Neutron Transmutation Doping Conference
1--3 June, 1982

(11). YANG ZHEN
THERMAL NEUTRON SCATTERING IN IAE, CHINA
International Conference on Scattering in the 90's 14--18 January, 1985

(12). THE INTERNAL REPORTS ON REACTOR OPERATION

INCIDENTS & RADIATION ACCIDENTS, IAE
Beijing, China (1958--1988)

(13). INTERNAL REPORT, PROTOTYPE PULSE REACTOR, IRERD
Chendu, China

(14). CN 85 1 00044B
THE DEEP WATER POOL TYPE HEATING REACTOR
Approval Desctiption for Application of Invention Patent
The Patent Office of China
Sept. 10, 1985