Fusion Effort in China

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FUSION EFFORT IN CHINA

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I. Overview

Two years ago, the National Science Conference was held in Beijing. Eight major items were proposed to be the emphasis of the national long-term development program of science and technology. The search for energy sources is one of these eight items.

This spring, at the Congress of the Chinese Nuclear Society, it was announced that nuclear energy should play its role in the long-term energy source program. Although China is rich in various energy resources, when averaged over its large population it is still not enough for substantial further development of the country. In addition, the distribution of energy deposits is not uniform; coal and water power are concentrated in some regions while there is a scarcity in other areas. Hence, nuclear energy (fission and fusion energy) is indispensable.

The exploitation of fusion energy is a long-term program. Because of its inexhaustibility and smaller impact on the environment, it is important for China to push the effort in fusion research.

The fusion effort in China is under the auspices of the Second Ministry of Machine Building and the Academy of Science. The State Science and Technology Committee takes charge of coordination. Table 1 shows the four main institutions in fusion research.

From Table 1 we can see China's fusion effort is to "keep a variety of approaches, but put the emphasis on the tokamak".

II. EXPERIMENTAL FACILITIES

Closed Magnetic System

Table 2 lists the tokamak devices in China. Among these CT-6 is the first, which was in operation in 1974 at the Institute of Physics, Beijing (Peking). The evolution of the discharge has been an area of interest. A tangential neutral beam injection system of 6-7 A, 20 keV is being prepared.

The HL-1 (Toroidal Plasma Current Machine No. 1) is one of the major programs at the Southwestern Institute of Physics. Along with the construction of HL-1, four other torii were built at the Southwestern Institute of Physics. Those are Pre-Test Torus, Noncircular Tokamak, Mini-Torus and the Screw Pinch Torus. Extensive theoretical work has been done on the equilibrium, stability, and transport of the tokamak plasma. At the same time some theoretical studies on toroidally linked mirror systems as well as planar and three-dimensional stellarators have been conducted.

HL-1 is the first medium-sized tokamak in China. It has an iron core of 70 tons and a very heavy copper shell 5 cm thick. High-nickel non-magnetic alloy bellows were welded to form the inner vacuum liner. Part of the power supplies with a total rating of about 200 MW have been installed in the experimental building. HL-1 is scheduled to go into operation by the end of this year.

During the HL-1 construction period, our scientific and engineering personnel have experienced the design, construction, and installation of the device. For further experiments in physics, the preparation of diagnostics and data acquisition, we have updated our objectives as:

(1) the study of the build-up phase of the tokamak discharge. For the pulse range appropriate to an apparatus like HL-1, it is expected that the detailed behavior at the build-up stage will have far-reaching

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TABLE 1.

Name	Location	Number of Scientists and Technicians	Devices	Date
Southwestern Institute of Physics	Leshan, Sichuan	400	Tokamak 4 Mirror 2 Pinch 3	1970
Plasma Physics Division in Beijing Institute of Physics	Beijing (Peking)	70	Tokamak 1 Pinch 1	1970
Hefei Institute of Plasma Physics	Hefei, Anhui	200	Tokamak 1	mid 1970's
Laser Fusion Group in Shanghai Institute of Optics and Fine Mechanics	Shanghai	40	Laser System	~ 1973

TABLE 2. Tokamak

	R (cm)	a (cm)	B_t (kG)	I_p (kA)	n (cm^{-3})	τ (ms)	Ti (eV)	Te (eV)
HL-1	102	20	50	400	(10^{14})	(40)	(800)	
Pre-Test Torus	26	> 5	20	12	10^{13}			15
Noncircular Tokamak	48	10 x 25	10-15	180	(10^{13-14})		(1000)	(1300)
Mini-Torus	20	4.5	12	15	10^{13}	0.03		20
CT-6	45	9	20	50				300
HT-6	45	10	10	20				

effects on the later development of the discharge.

(2) the manipulation of this stage in conjunction with the procedure of heating, the gas supply and recovery, which are closely related to refuelling, to improve the performance of the apparatus;

(3) the study of plasma-wall interactions and the control of impurities;

(4) the scaling of confinement properties and plasma parameters as affected by the heating procedure.

After a first period of experiment it is planned to concentrate on supplementary heating to further improve the plasma parameters which can be attained.

Two of the four smaller torii, the Mini-Torus and the Pre-Test Torus have been useful for preparatory tests of various kinds. The two others, the Noncircular Tokamak and the Screw Pinch, are for follow-up studies.

HT-6 is an air-core transformer tokamak at the Hefei Institute of Plasma Physics. The previous CT-8 program has been stopped for the time being.

Open Magnetic System

A large Superconducting Mirror Machine was first assembled at the Southwestern Institute of Physics in 1975. Its total floor space is about 9000 m^2, total investment amounts to 20 M yuan (~ $13 M). Some of its characteristics are given in Table 3.

TABLE 3. Mirror Machines

	B (kG)	Spacing between mirrors (cm)	Mirror Ratio (axial)	Configuration	Vacuum (torr)	E_i (keV)
Superconducting Mirror Machine	15-25	48	1.75	Simple	1×10^{-9}	100 ~ 150
Small Mirror	0.71	48	1.75	Min B	10^{-6}	

This is the first time that we have made such a large superconducting magnet. A series of preparatory experiments have been performed, such as 1) an investigation of the critical currents of wires and cables; 2) the effects of the mechanical stress on the critical currents; 3) the measurements of the propagation velocity of the normal resistance zone and the minimum propagation current in the coils; 4) the protection of the superconducting magnet system; and 5) indium supersonic soldering for cable joints with a resistance of less than 10^{-9} Ω. Through the experiments on a 15 cm bore magnet, we examined the technology of the mirror coil, which is a 29 cm bore superconducting magnet, and determined the optimum structure. As a result of these experiments the mirror coils reached the required design.

At the same time, a cryogenic workshop was built to supply the liquid nitrogen and liquid helium, which are produced with Chinese-made liquifiers.

A neutral beam of 100 keV energy is injected into the mirror. Its initial ion current is 1 A. A 3 A DC power supply facility of 300 kV with stability of 0.5% was designed for the ion source. We have built another 20 kV, 3 A ion source of multi-aperture type and are now attempting to develop a 20-50 A ion source.

Before the Superconducting Mirror was constructed a copper wire mirror machine was built with the minimum B configuration. Some experiments of confinement and plasma heating have been done with the normal magnets.

Mirror research was started much earlier at the Institute of Atomic Energy, Beijing. A smaller configuration of magnetic mirrors with slow magnetic compression and plasma gun injection recorded a temperature of about 300 eV at a density of several times 10^{13} cm^{-3}. In the middle 60's, a mirror machine program was planned. It led to a large Superconducting Mirror Machine program in 1970. A giant effort has been made to overcome engineering and other difficulties. During the difficult times of the mirror program we tried to find a way to reduce the end loss of the Mirror. Fortunately, both Chinese and American scientists thought of the asymmetric multiple-mirrors independently. Recently we have been attempting to publish our findings in a cooperative way.

Fast Pulsed Discharges

Z-pinch and θ-pinch work was started in the late 50's. Table 4 shows the main pinch devices in China.

A high beta belt-pinch type torus, GBH-1, is being constructed at the Institute of Physics, Beijing. The elongated plasma would be heated by fast magnetic compression. A separate set of toroidal field coils is used in addition to the plasma current-induced coil so that the safety factor q can be changed in a wide range from $q > 1$ to $q < 1$. A capacitor bank of a total energy of 2.7 MJ will be used to power this apparatus which has an Al_2O_3 vacuum chamber of outer radius 65 cm, inner radius 25 cm, and height 100 cm.

There are two linear theta pinches and a toroidal screw pinch in operation at the Southwestern Institute of Physics. Neutron yields of up to 10^6 per pulse have been observed on the linear theta pinch. They have been doing some negative bias field experiments, where the field is similar to a reversed-field configuration.

Plasma Focus Experiments

Plasma focus experiments have been done by several groups.

Maximum neutron yields of 4×10^9 per pulse were measured at the Institute of Atomic Energy. This occurred in a 40 kJ Mather-type plasma focus device. The scaling law of neutron yields was found to be roughly proportional to I^4 where I was the discharge current at the instant of focus formation. An anisotropic distribution of neutron energy was observed.

Laser Fusion Research

Experimental and theoretical research of laser fusion is being conducted at the Shanghai Institute of Optics and Fine Mechanics.

TABLE 4. Pinch

	Size (cm)	B (kG)	I (kA)	E (MJ)	τ_d (μs)	n (cm^{-3})	T_e (eV)	T_i (eV)	τ_E (μs)
GBH-1	height 100 O.R. 65 I.R. 25	16	400 ~ 600	2.7	(200)	(10^{14-15})	(100)		(100)
θ-Pinch	length 20 radius 1	45		.065		3×10^{16}	40 ~ 50	1000	
Toroidal Screw Pinch	major 29 minor 6	13	30	.080	30	$0.5\text{-}1 \times 10^{16}$			3-4

Soon after the operation of the first high power ruby laser in 1963, it was suggested that neutrons could be obtained by heating deuterium-containing materials with high power lasers. Work on fusion began there in 1965. In 1973 a 10-GW neodymium glass laser was used to generate neutrons by irradiating flat deuterium-containing targets with four-nanosecond pulses at power densities of 10^{13} to 10^{14} W per square centimeter. A yield of more than 2×10^4 neutrons per pulse was obtained. In 1975 a six-beam neodymium glass laser system was put into operation, which can produce 100 GW per beam in 100 psec pulses. In present experiments 50 GW in each of two beams are focusable on glass shell microballoon targets filled with deuterium or neon. A one dimensional hydrodynamic computer code was used to simulate the laser implosion. The assumption of the heat conduction coefficient was made to fit the experimental results.

III. Fusion Reactor Studies

Conceptual design studies of both pure fusion and fusion-fission hybrid systems have been made. Computational work on a number of blanket compositions and energy retrieval schemes has been done. These studies point to the great importance of further research into energy conversion and reactor materials. We are attempting to develop the understanding of the physics involved in the fusion technology.

IV. Future

Since the 1950's, China has been doing research in Controlled Nuclear Fusion. More than twenty years have past. The fusion research in China has reached a stage when it should review the past and consider the next step. We are adjusting the pace of our fusion research. However, there are some aspects which are fixed:

1) Particular attention is given to both plasma physics and fusion technology.

2) Full use of existing devices is attempted to obtain more physical results.

3) Further development of scientific exchanges with the scientists and engineers around the world to promote better understanding of the problems facing fusion.

V. Acknowledgments

The author wishes to thank the Chinese colleagues and the American friends at the University of Wisconsin and Princeton University for their help in preparing this paper.

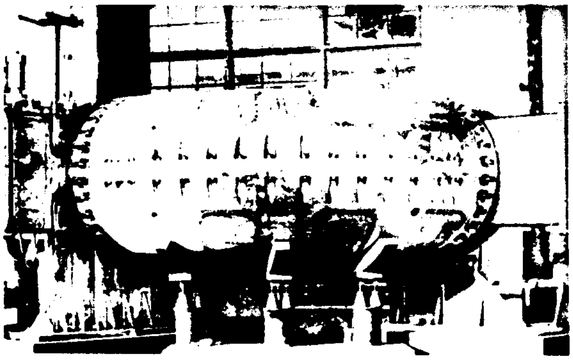

FIGURE 1. Vacuum vessel and copper shell for HL-1.

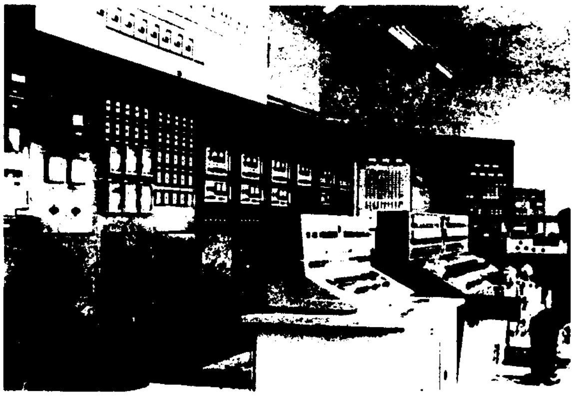

FIGURE 4. Mirror Facility Control Room.

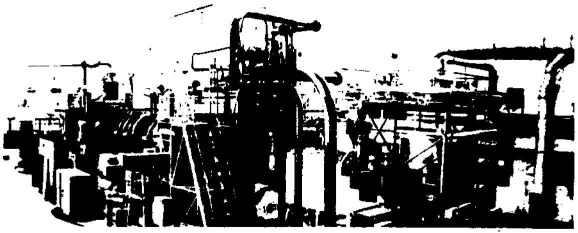

FIGURE 2. Superconducting Mirror Machine Experiment.

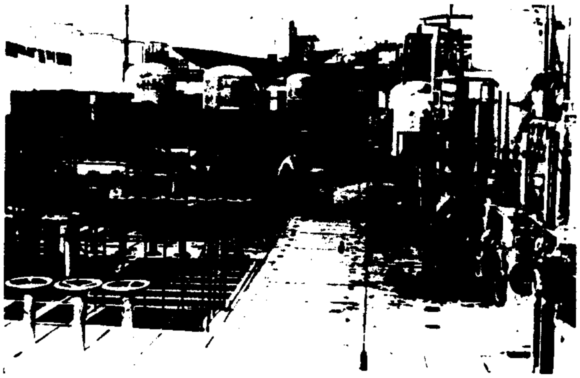

FIGURE 3. Cryogenic Workshop for Superconducting Mirror Machine.