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A PHYSICIST'S VIEW OF SCIENCE AND TECHNOLOGY IN CHINA[1]

A Chinese-born scientist reviews the Science Policy for Modernization in China, as formulated by the Chinese leadership in 1978, its initial results, and some future prospects. He uses information derived from his long-time personal experiences and many on-the-spot observations; discussions with his Chinese friends, former colleagues, and students; and professional opinions on China's Modernization expressed by visiting foreign experts.

PROLOGUE: A SHORT ACCOUNT OF CHINA'S CONNECTION WITH SCIENCE AND TECHNOLOGY

Ancient and medieval China are universally credited with the invention of the abacus, the magnetic compass, gunpowder, papermaking, printing, and mechanical clocks, and with early observations of astronomical phenomena and earthquakes. However, for more than 300 years, China's place in science and technology had fallen into a dismal abyss, while the Western world reached great heights in these fields through the Renaissance and the periods of Scientific and Industrial Revolution. After the turn of this century, the gap in science and technology between the West and the East kept increasing at an accelerated pace. The only exception was Japan, which in the past was deeply rooted in China-centered culture but which, from about the middle to the end of the 19th century, turned toward the West in a "Reformation" movement of learning first European and later American science and technology. Japan has been so much imbued with Western scientific influence that, despite the defeat in World War II, she now stands on a par with the world's strongest economic powers.

After the turn of the century, particularly after the Manchu dynasty was overthrown in 1911, China tried in a halfhearted manner to follow the pattern set by Japan. Using Boxer indemnity funds from the United States (later also from England), China began yearly to send abroad teams of young students, largely to the United States, to study physical and engineering sciences and, in some cases, liberal arts. I was among these one to two thousand young people who, after roughly five years of study (with degrees up to the Ph.D.), mostly returned to China to serve in educational and research institutions. Those people and the students they trained (e.g., budding stars like C. N. Yang and T. D. Lee of parity nonconservation fame), particularly during the 1937-45 Sino-Japanese War, were, factually speaking, the pillars of the Chinese academic society. They did not, however, contribute much to the advancement of Chinese science and technology, principally because of the disruptions caused first by the tumultuous civil strife among the Chinese warlords and later the prolonged Sino-Japanese War.

After the Chinese communists succeeded in their revolution in 1949, the Russians sent a large number of technical experts to help China's reconstruction and exerted great influence in all areas of Chinese society, including science and technology. China sent to the Soviet Union a number of scholars to do research and a sizable number of students to pursue scientific and technological studies. Upon their return, many of these scholars became leaders in their own fields in China. While China appreciated Russian technical assistance, she reacted with intense bitterness and immense animosity to being treated as a subservient satellite. Political-ideological considerations notwithstanding, the Middle Kingdom (the name of China in Chinese) could not bear the humiliation of subjugation to its traditional enemy. (Historically, Czarist Russia had taken enormous regions of China's territory.) This led to the inevitable open split in 1960 in the technical and economic relations between China and the Soviet Union.

The years between 1960 and 1970 marked a most tumultuous period for China in its science and technology. During 1960 to 1965, research and education were in a state of recuperation from the loss of technical help from the Soviet Union. Between 1965 and 1970, scientific research and academic education were greatly disrupted by the Cultural Revolution; academic education, in particular, was almost completely stopped by Mao's Red Guards and the reign of terror by the "Gang of Four."

The rapprochement between the United States and China, brought about, oddly enough, by the Ping-Pong diplomacy in 1972, is too well known to be retold. Scholarly communication and technical exchange between the two countries were fairly well established long before reciprocal diplomatic recognition took place in 1978.

The doctrine of "Four Modernizations," namely, the modernizations of agriculture, industry, science and technology, and national defense, was conceived and advocated by Premier Chou En-lai for many years against the opposition of the ultraleftists in the government. Two years after Chou's death, the legislation for Modernization was formally adopted by the National People's Congress in February 1978. This led to the formulation and official announcement of China's new science policy in March 1978.

SCIENCE POLICYMAKING IN CHINA'S POLITICAL STRUCTURE

Figure 1 shows China's political structure as seen in 1977, which is still mostly valid today. The concrete plans for science and technology are the responsibility of the State Science and Technology Commission in collaboration with the Chinese Academy of Sciences and the Ministry of Education. These three departments are independent ministries under the State Council, which theoretically answers to the National People's Congress but in practice to the Politburo of the Chinese Communist Party. On 29 June 1981, the Central Committee of the Communist party elected Hu Yaobang as Party Chairman and Zhao Ziyang, who is concurrently Premier of the State Council, as Vice-Chairman. Fang Yi is Vice-Premier and Minister in charge of the State Science and Technology Commission. Lu Jiaxi, a physical chemist, was recently elected by the entire membership of the Chinese Academy of Sciences to be the new president of the Academy.

In March 1978, the Central Committee of the Communist Party called for China's first National Science Conference in Beijing, which was attended by 6000 scientists and adminstrators. The conference was called explicitly to make a new science policy for China's Four Modernizations. The then Party Chairman Hua Guofeng and Vice-Chairman Deng Xiaoping made key speeches signifying their approval and

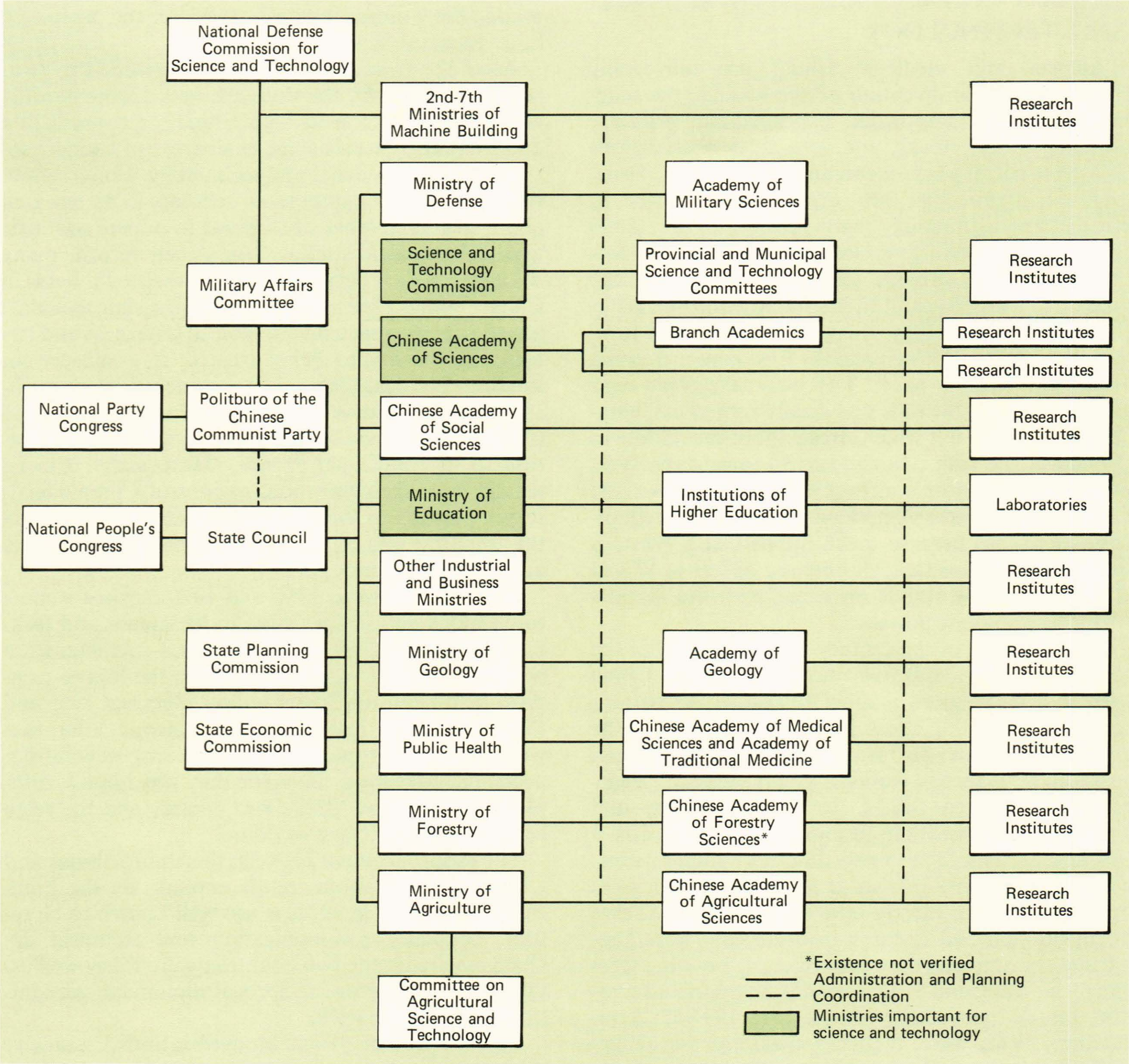

Fig. 1—The political structure of China, showing the national organization for science and technology.[2]

support of China's new Science Policy for the eight-year period 1978-85. Fang Yi, as the head of the Commission, outlined eight spheres of science and technology to be the highest priority targets.[3] They are agriculture, energy, materials, electronic computers, lasers, space, high-energy physics, and genetic engineering. Progress of work in these spheres is to be achieved within this period to the degree that will enable China to approach or reach the advanced world levels of the 1970's in a number of important branches of science and technology. This is meant to lay a solid foundation for China to catch up to—or even selectively surpass—advanced world levels in the following 15 years until the year 2000, when it is hoped China will become a modern and powerful socialist country.

Three of the eight years have already passed. Some adjustments and modifications to the initial plan have already been suggested and made. Some programs (like high-energy physics) were not to be over-budgeted to the detriment of the goals of the overall national economy (e.g., raising the people's standard of living). The goals in genetic engineering could be very beneficial to agriculture and biomedical engineering, but China is not fully prepared to reach out to the far frontiers of molecular biology. Some people contend that the Science Policy is too ambitious and unrealistic. Still others (including myself) put forth the opinion that basic science, both in research and education, should be well cultivated within this period to prepare for a fuller growth during the following 15 years. Nevertheless, the main body of the Policy seems to possess a great deal of sustaining strength as the first step in China's modernization.

We will discuss the ramifications of the eight comprehensive scientific and technical spheres as outlined in the Science Policy.

AGRICULTURE

In all of its long history, China has been basically an agrarian society. Nearly 80% of its enormous population of approximately one billion people live and work in agricultural communes in rural areas of the country. Only roughly 10% of the land is under active cultivation. Using principally human and animal labor and age-old methods of agriculture, the production of food has been very low. In spite of these formidable handicaps and of emergencies resulting from natural disasters, China has been able to feed its entire population,[4] only occasionally resorting to some necessary importing (for example, four million metric tons of wheat from the outside world in 1976).

It is only natural that the modernization of agriculture has been given the topmost priority by the Chinese Government. An increase in food production can be expected from (a) building a large number of water reservoirs for irrigation and flood control, (b) mechanizing of farming wherever it is physically and economically practicable, (c) land reclaiming in various parts of the country, (d) advancing the techniques of scientific farming, and (e) offering incentives to farmers for free marketing. We will make a few remarks on the areas where some progress has been achieved.

In the past 10 or more years, approximately 84,000 water reservoirs have been built, with a capacity of 400 billion cubic meters.[5] I have visited the enormous engineering project of the Red Flag Canal in Linxian, Henan Province; a network of five high-capacity water reservoirs at Meishan, Anhui Province (see Fig. 2); and a half dozen other reservoirs in the northeast and in other provinces. About 48% of the cultivated land, predominantly in northern China, has irrigation facilities. There are five times as many water reservoirs as there are in the United States and seven times as many as there are in the Soviet Union.[5] This indicates that China has done quite well in irrigation and flood control. Yet there occurred this year a severe drought and a horrendous flood, both in Henan Province, causing China for the first time to swallow its pride by inviting international relief. (In recent months, two other catastrophic floods have occurred on the tributaries and the main stream of the Yangtze after extraordinarily heavy rainfalls in Sichuan Province. They caused the loss of nearly a thousand lives and damaged the river beds with eroded-soil silts.) This shows that more new irrigation, flood control, and reforestation projects are critically needed.

Mechanization of farm work includes the use of machinery for plowing, sowing, harvesting, and threshing (see Fig. 3). It is particularly adaptable to the sizable plains in the north and northeast, which are grain-growing regions. It is not quite suitable to the rice-growing south, where the small terraced paddy fields leave rather little room for the efficient operation of farm machines.[6] Even in the north, tractors are used more for plowing than for anything else and not enough machines are used for seeding, harvesting, transplanting, etc. This means that mechanization of farming in China varies greatly with local conditions and probably will not be widespread for some time to come.

A land reclamation project in the northeast and the Xinjiang areas for grain production, utilization of the Loessical Plateau for livestock and fruit trees, development of Hainan Island for tropical crops, and the use of other wastelands have apparently not yet been put into operation.

Scientific farming is in an active state in terms of plant breeding and genetics,[7] plant protection (control of insects and plant diseases),[8] proper use of fertilizers (Chinese farmers use a lot of human- and animal-waste fertilizers[9] and an inadequate amount of chemical fertilizers), and animal sciences[9] (largely, techniques of animal production), but no comprehensive scientific research is involved.

The introduction of a free market for farmers by Zhao Ziyang, while he was Governor of Sichuan and before he became the Chinese Communist Party Vice-Chairman and Premier of the State Council,

Fig. 2—Map of China with names of cities and places referred to in this article. The names of cities have their first letters capitalized, while the names of provinces are capitalized.

caused a dramatic upturn of the agrarian economy by offering to the farmers a material incentive for higher production and marketing. They found themselves suddenly richer and elevated to a comparatively better standard of living. This seemingly small but actually very significant change in policy has rapidly spread like a shock wave over the country and is bound to have great repercussions in the agricultural economy.

ENERGY

The sphere of energy occupies the second most important place for the Modernization of China, immediately after agriculture. We will first consider three forms of fossil energy: coal, crude oil, and natural gas. They represent the transformation of solar energy accumulated and stored on earth through millions of years. We will then discuss electric power generation.

Coal

China has plenty of coal underground. My native province of Shanxi has so much coal reserve that a German geologist was said to have estimated, perhaps a century ago, that the reserve was enough to satisfy the whole world's consumption for thousands of years. It may have been a wild guess, but the extraordinary abundance of Shanxi's coal reserve has indeed stood up well with modern prospecting. However, the immediate question is not one of reserves

Fig. 3—Harvesting machines used at the Hebaohu Farm in Wuhan.

but of production. Nowadays the Datong Coal Mine is the biggest supplier of China's coal needs since the Kailuan Coal Mine in Tangshan (almost halfway between Tianjing and Qinhuangdao) was all but totally destroyed during the disastrous earthquake in 1976. I visited the Datong Mine in 1977 and saw its deep-mine colliery (most Chinese mines are of the deep rather than the surface type, the deepest being more than 900 meters in shaft length). The new colliery has roughly 17,000 meters of tunneling and about 58,000 square meters of floor space, which was prepared in less than four years. According to coal mining experts I consulted, Datong's mining technology is very antiquated; this is true of most other Chinese coal mines, with the possible exception of the Kailuan Mine, which was the largest and most modernized before the earthquake.

In 1974, I visited the Fushun Coal Mine (near Shenyang, in Liaoning), where some surface mining was also done. The difficulties with Fushun are the same as those with all the others: only about 30% mechanization, in comparison to 100% in the United States and the Soviet Union; inferior mining equipment, mostly made in China; and poor techniques in coal preparation. The overall coal mining technology lagged behind the West by at least 15 years.

In spite of the backwardness of China's coal mining industry, well-confirmed statistics have shown that during the period between 1949 and 1978, coal production in China grew from 32 to 618 million metric tons, thus raising China from eighth to third place in the world,[10] surpassed only by the Soviet Union and the United States.

Nowadays, China is more than eager to push hard for the modernization of its coal industry, which, after all, supplies 70% of the nation's energy resources.[10] China was negotiating an investment of $6 billion in 1978 to buy advanced coal mining equipment from West Germany, Great Britain, Japan, Poland, and the United States.[10] If the negotiations were successful, it can be presumed that this huge investment will bring tangible progress to China's coal industry.

Crude Oil

The existence of fossil oil under any of China's territorial land or water was unknown before 1950. Before that time, signs in every big city advertised the products of the Standard Oil Company, which held the monopoly. Practically all foreign geologists predicted that there would not be a drop of oil in China. During all this time, a famous Chinese geologist by the name of Li Siguang postulated the existence of fossil petroleum in the "subsidence belt of a neocathaysia structure" and predicted that China should have rich oil fields, for reasons diametrically different from the prevailing theories of geological formations for petroleum deposits. Because of Li's great prestige and strong backing by the political leadership, a nationwide search for oil was conducted by many thousands of resourceful young geological workers, known as "prospecting cadets," who explored China's great expanse of land, looking for symptoms of petroleum formation. After going through many years of countless disappointments in trial and error, they were finally rewarded with the discovery of the giant Daqing oil field in Heilongjiang in September 1959. It was a moment of triumph, jubilation, and national pride. The big point was: "Now, China does have oil."

I visited the Daqing oil field and its refinery in 1977; by then it had grown to a gigantic establishment. As a Chinese-American, I was truly elated to eyewitness for the first time the ejection of a dark crude-oil jet from a valve-controlled pipe to a testing swamp tens of meters away.

Discoveries of other oil fields[11] followed quite quickly: Shengli in Shandong between 1960 and 1964; Dagang near Tientsin between 1964 and 1967; Panshan in Liaoning in 1964; and Renqiu in the early 1970's.[12] There were, of course, many relatively small oil fields discovered in other regions of China before and after Daqing.

I should have mentioned earlier that in August 1974 I visited the Donfanghong Oil Refinery and its associated petrochemical plant at Fangshan District (near Beijing), which were built in 1969, three years later than the Daqing Refinery. Dongfanghong is a smaller version of the Daqing Refinery and produces practically everything that the latter does, except for aviation gasoline.

The next major development in China's petroleum industry was the building of two long-distance pipelines in the mid-1970's. One pipeline connects Daqing with the ports of Qinhuangdao[13] and Dalian on the Bohai Gulf. The section between Daqing and Qinhuangdao is 1152 kilometers long. Building it required the most arduous hand-tool labor of thousands of people. The other (unconfirmed) long-distance pipeline of 1000 kilometers between Qinghai and Xizang (Tibet) was very difficult to construct and measures up to international standards.

New ventures of offshore oil extraction have been undertaken in recent years by China, with help from foreign investment and technology, both in the Bohai Gulf and in the East and South China Seas. Prospecting for deep-water oil has been successful in a number of exploratory oil drillings. The building of oil-drilling derricks is in process at the Dalian Shipyard, and an offshore oil-drilling rig is in operation in the Beibu Gulf (see Fig. 4) of the South China Sea.[14]

Using obsolescent oil extraction equipment largely of domestic manufacture and an oil technology at least 10 years behind that of the West, between 1949 and 1978 China has risen by sheer will from practically no oil to an annual production of 104 million metric tons of crude oil. China is now an oil-exporting nation ranking with Libya, Kuwait, and Nigeria.[15]

Natural Gas

Last year I spent one month in Chengdu, capital of Sichuan Province. Weird stories of ghost-like blinking lights floating in the distant darkness have been a part of the folklore there for a long time. They are now explainable as streams of natural gas escaping from the ground sources. Most of these sources are concentrated in Sichuan. There is now a total of more than 1000 kilometers of natural gas pipelines connecting neighboring regions for industrial use. Recent data show that China's natural gas flow reached about 52 billion cubic meters, elevating China to the status of the world's fifth largest producer of natural gas.[15]

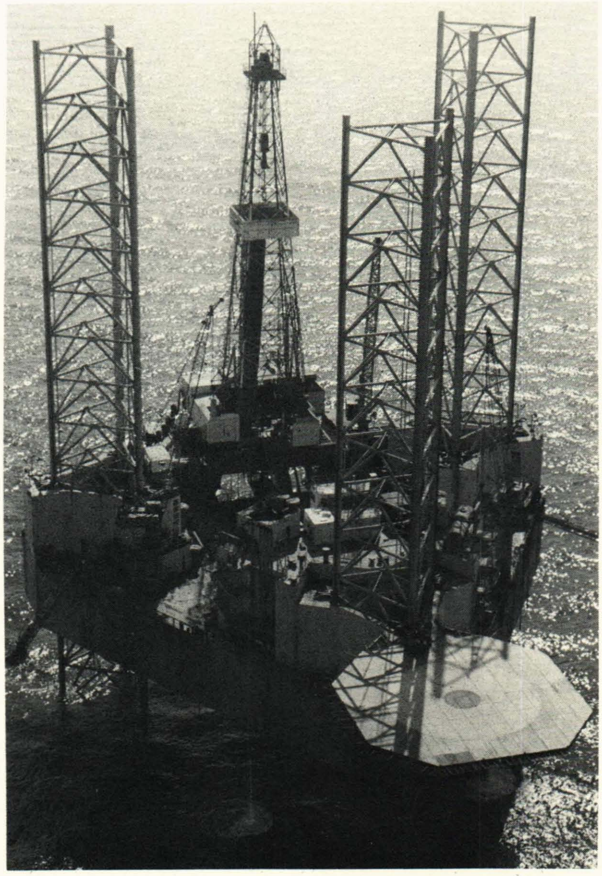

Fig. 4—An offshore oil-drilling rig used in the Beibu Gulf of the South China Sea.

Electric Power Generation

The total electric power generated in China is about 40 gigawatts, only 8% of the United States total, too little for its own needs. Thermoelectric power generation using largely coal as fuel represents about 70% of the overall generating capacity, and hydroelectric power supplies the remaining 30%.

The largest domestically built thermo- or hydroelectric turbogenerator has a moderate power capacity of 300 megawatts, which is a third to a fourth the size of the world's largest. The only redeeming feature is that China pioneered a new technology in making a 300 megawatt turbogenerator with both the rotor and stator simultaneously water-cooled.[16] Now the twofold cooling is used on much larger generators by other countries.

Although China has the world's largest hydroelectric potential,[17] its hydroelectric power generation is very underdeveloped. A generous estimate of the total hydroelectric power is no more than 12 gigawatts. The largest plant, Liujiaxia on the Huang (Yellow) River in Gansu Province, generates about 1.2 gigawatts. In 1978, I visited this plant with its big concrete dam and a reservoir of about 5.7 billion cubic meters. It has five big generators, including China's only 300 megawatt hydroturbogenerator.

When the water level in the reservoir is high, visitors are often given the treat of seeing a spectacular display of the water discharge through the spillway. Yet Liujiaxia does not even rate among the world's 20 largest plants. Besides Liujiaxia, there were at that time only nine hydroelectric stations whose generating capacity exceeded 300 megawatts.

While the number of relatively large hydroelectric stations is rather small, in 1979 there were 87,000 small rural hydroelectric stations, each generating 50 kilowatts or less. The sum total of the hydroelectric generating capacity of the small stations amounts to about 30% of China's hydroelectric power.

In October 1980, I went by boat downstream on the Yangtze River, passed by the famous Three Gorges, and then the Gezhouba Water Conservancy Project near Yichang, Hubei Province (see Figs. 5 and 6). The grand plan of the project would allow ships of very large tonnage to navigate through by means of lock gates as in a canal and at the same time make it possible to generate China's greatest hydroelectric power.[18] There are two engineering phases. The first phase, involving the construction of Watergates No. 2 and No. 3, is largely completed. Watergate No. 2 controls water flow rate for the generation of hydroelectric power and a water discharge gate. The power to be generated is designed at about 170 megawatts. Watergate No. 3 provides two lock gates, one allowing 3000-ton ships to go through and the other allowing navigation of 10,000-ton ships. The second engineering stage was begun in January 1981 by cutting off water by the Watergate No. 1 lock and undertaking a test run on the navigation of large-tonnage ships through the second lock of Watergate No. 3. The second phase, as well as the entire gigantic Water Conservancy Project, will be completed in

Fig. 5—A shipping gate, 19.7 meters wide and 34 meters high, used on the Yangtze River at the Gezhouba Water Conservancy Project.

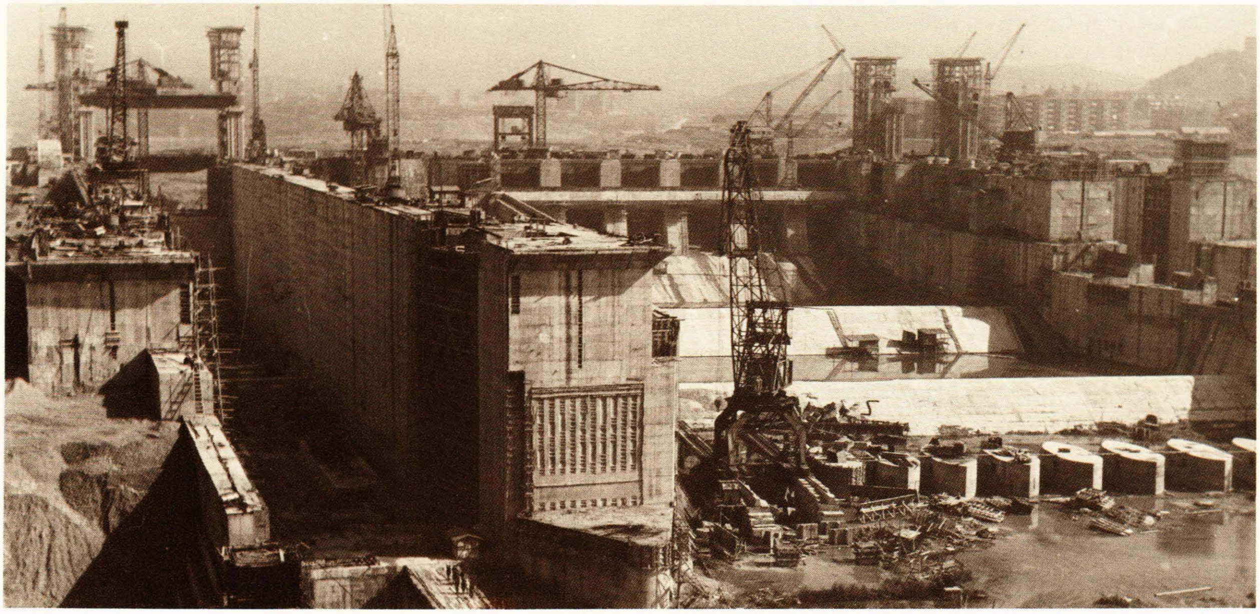

Fig. 6—A view of the principal part of the Gezhouba Water Conservancy Project on the Yangtze River.

1985. The ultimate power-generating capacity of the whole project is 2700 megawatts. The project is generally considered by world standards to be a very large, advanced-construction undertaking.

Nuclear, Geothermal, Solar, and Biogas Energy

Although the eight-year modernization program called for the use of nuclear, geothermal, and solar energy, it seems that China is temporarily doing either nothing or only a minuscule amount about this. In a small way, however, China is leading the world in small-scale biogas (principally methane) technology and production. With its long rural agricultural tradition, China is well adapted to develop and use this kind of limited but useful energy in the countryside.

MATERIALS

Steel is undoubtedly the most important material in industry. China has at least nine large iron and steel works: Anshan (in Liaoning), Wuhan (in Hubei), Shanghai, Beijing, Taiyuan (in Shanxi), Benxi (in Liaoning), Baotou (in Inner Mongolia), and Chongqing and Maanshan (in Anhui), with Anshan leading all the rest. There are 14 other medium-sized plants in cities all over the country.

I visited the Anshan Works in 1974. Anshan had then 11 blast furnaces, 25 open hearths, 2 large basic oxygen furnaces (the most modern type), various mines and sintering and beneficiation plants, and blooming and finishing mills of various types, including plate, hot strip, rail, pipe, and tube mills. A former student of mine, a high ranking engineer in Anshan, told me confidentially that the annual aggregate output of Anshan steel was 6.5 million metric tons (confirmed later by another source).

I visited China's second largest steel mill, the Wuhan Steel Works, on the Yangtze River in 1977. I had the good fortune of being shown around by the Associate Chief Engineer, Zhang Chunming. He told me that their raw iron was principally supplied by the Daye Iron Works (also in Hubei Province). Wuhan had several blast furnaces, and a third large unit was installed in 1969. Afterwards it added one more large open hearth furnace to the old Soviet ones. Later it added one larger sintering plant and various other mills. Most of the steel made in China contains tungsten as the principal alloy because China is among the richest tungsten suppliers. (American steel works used molybdenum as a good substitute for tungsten during World War II.) Sometimes Chinese steel works use manganese as the principal alloy. (Anshan Works supplied manganese steel for building the largest Yangtze River bridge.) The annual steel production of the Wuhan Works was at least 2.5 million metric tons (a 1974 figure).

At the time of my visit, China had already contracted a large purchase for the Wuhan Works from Japan and West Germany, including a 3-million-ton hot strip mill, a 70,000-ton silicon steel mill, and a 1-million-ton cold strip mill.

Most surprisingly, Engineer Zhang told me near the end of my visit of a knotty problem that the Wuhan Works was facing. He asked me if I might contact some American steel experts for a solution. The problem originated from the Japanese insistence in their contract that the finished silicon steel must not contain more than 0.01% copper or else the Nippon Steel Corporation would not honor the warranty. (It was said that since the Japanese had hardly any copper and did not have much experience with it, they were afraid that even a small amount of copper might hurt the quality of the silicon steel.) Yet the Wuhan Steel Works had always used raw iron from the Daye Iron Works that had an unusually high copper content. It would be prohibitively expensive for the Wuhan Works to reduce the copper content of the Daye raw iron to 0.01%. In this great dilemma, Engineer Zhang saw a ray of hope from an American publication during 1974 or 1975 to the effect that laboratory experiments showed conclusively that a high quality silicon steel can contain 0.3 to 0.5% of copper with some beneficial rather than harmful effects. Thus Engineer Zhang earnestly sought help from me to contact some authoritative source for information. Upon my return to the States, I finally located a Chinese-born expert (Hu Xun) in the U.S. Steel Research Laboratory who happened to be among the best authorities on this subject and who was willing to make a special trip to China to solve the problem. I derived much satisfaction in lending a layman's hand in establishing a connection between exactly the right parties.

It was reported in 1978 that China's overall production of steel in that year was more than 31.7 million metric tons, which would place China at about the same production level as Great Britain, France, and Italy but behind the top four producers, the United States, the Soviet Union, Japan, and West Germany.[19]

Unfortunately, China's prospect of expanding steel production has encountered a setback in the past year or two. In 1980, China found that her new project for the Baoshan Iron and Steel Works in Shanghai to buy complete sets of modern steel-making equipment from Japan went beyond her economic capability. Doomed by all-around poor planning from the very beginning, this project had to be canceled, as one among many economic retrenchments.

As to the materials problem on other fronts, I learned that China's three leading export metals are tungsten, tin, and antimony, of which tungsten is perhaps the most important.[20] Other nonferrous metals that China has in great abundance are molybdenum, manganese, and vanadium. Fang Yi vowed in China's Science Policy to "make China one of the biggest producers of titanium and vanadium in the world." There is no question about the vanadium, but I have not yet found any reference to an abundance of titanium; perhaps titanium and vanadium are among the polygenetic deposits.

More importantly, China has a large amount of iron ore, but it is generally of low quality. The metallurgical technology of efficiently and economically upgrading the iron concentrate is a matter of high industrial priority.

China has the world's most abundant supply of rare earth metals. (John D. Baldesschwieler of the California Institute of Technology has aptly observed[21] that if the rare earth elements had been discovered in China, the word "rare" would never have been used. Baldesschwieler further remarked that almost all chemical research laboratories he visited in 1978 were looking for rare earths and rare earth compounds.) The Jilin Institute of Applied Chemistry worked on the separation, extraction, and purification of rare earths.[21] In the West, the chemists find that the rare earth ions have very similar chemical properties because they are apt to be trivalent and their outermost electron shells have the same configuration as neutral xenon. Hence, their chemical separation in tolerably pure form was accomplished only long after their discovery.

The Jilin Institute also works on the synthesis of rare-earth compounds and alloys, particularly semiconductors.[21] For instance, for every compound involving selenium (which, like sulfur, is in the VIth column in the periodic table), they can make a similar compound involving the rare earth gadolinium. Also, they can dope a compound like lanthanum trioxide (which is most likely a semiconductor) with a small amount of gadolinium substituting for lanthanum, thus making a rare-earth-doped laser material. Such examples can go on.

Scientists at Fudan University in Shanghai have been looking for rare-earth compounds (presumably gases) that, when excited by ultraviolet radiation, would convert it to visible light for use in fluorescent lighting. The ultraviolet radiation can be produced by electrical discharge in the lamp.

ELECTRONIC COMPUTERS

Modern computer technology in the West owes its start to John von Neumann's mathematical concepts and its practicality to semiconductor electronics. Seeing the great potentiality of computer technology, China started to develop electronic computers in 1956 and, during the ensuing years, established computer research institutes in Beijing, Shanghai, and at least four other cities.

During the past 25 years, China has pursued the front-runners by making some 40 models of its own. The Chinese made full use of the "prototypes" purchased from Japan, West Germany, the United States, and a few other countries, but their technology usually lagged behind the leaders by 10 to 15 years. For instance, one foreign observer reported in 1977 that a computer made in the Beijing Institute was capable of performing 2 million operations per second[22] (a speed of 5 million operations per second was expected in 1978[23]), but I learned that the speed achieved in the West was probably five to ten times greater.

Chinese computer scientists often complain about their weakness, particularly in the software department, but foreign observers also see weaknesses in Chinese input and output equipment and in storage peripherals.[22] They do not yet do much data processing (real-time or not), multiprogramming, timesharing, random access to memory, or information retrieval.

In recent years, there has been widespread interest among the Research Institutes of the Chinese Academy of Sciences and the computer departments of at least five key universities in doing work on large scale integration (LSI).[24] This is again a follow-up of the Western development of continually increasing the scale of circuit integration (hence higher density of computer elements). There is a clear indication that the speed of operation of Chinese-made computers will be appreciably increased.

As the computer memory gets larger (say 128,000 bits), it becomes highly desirable to develop a method of random access to the memory. This was done in 1978 at the Shanghai Institute of Metallurgy, which developed an LSI system having random access capability. The system's bipolar circuits are identified by the Institute researchers as ECL 256 bit and ECL 1024 bit. The address access time is 28 nanoseconds, power dissipation is 500 milliwatts, and the chip size is 2.8 × 3.1 millimeters.[25]

Recently I learned that the Institute of Computer Technology in Beijing now has facilities for real-time processing, multiprogramming software and hardware, computer graphics, and information retrieval.[24] Also, in cooperation with three other manufacturers, Beijing University completed a laser computer unit capable of compiling and typesetting Chinese characters (see Fig. 7).[26]

As a matter of management, it seems to be a good idea for the Chinese computer industry not to race too strenuously with the ultrafast developments in the West but to spend at least half of its effort in producing large quantities of workhorse computers with only a modest speed, to satisfy nonsophisticated, everyday demands of many sectors of Chinese society. Or if self-manufacture is not economical enough, another good approach is for China to buy "obsolete" computers from Japan or the West, often available at fantastically reduced prices.

LASERS

Laser development in China was already much emphasized several years before the announcement of the new Science Policy, which inevitably provided further impetus. The Chinese research efforts on lasers and semiconductors are the only two fields in which visiting Western authorities are willing to concede a five-year shorter lag behind the Western world (the lag for most branches of science and technology is generally at least 10 to 20 years).

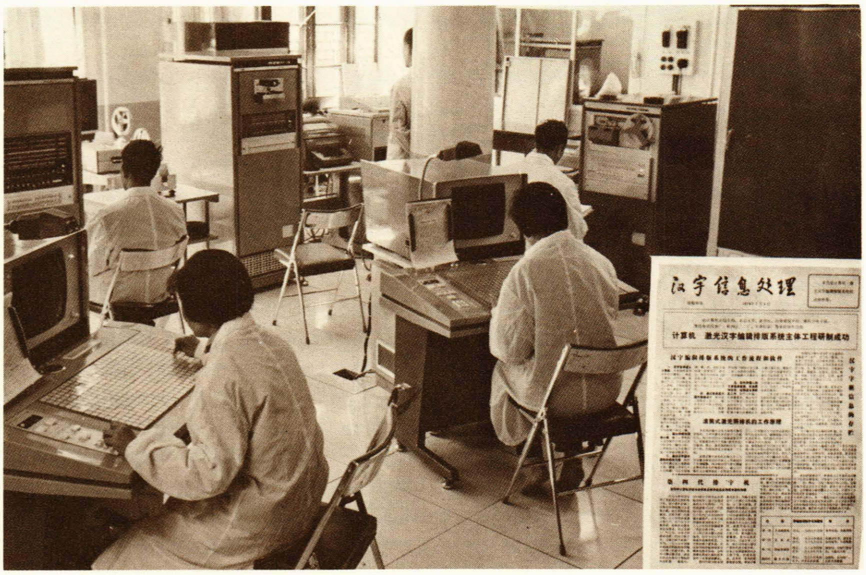

Fig. 7—A laser-controlled computer project in Beijing for compiling and typesetting Chinese characters.

During my past extensive trips to China since 1972, I have visited, among others, six institutes (Physics, Semiconductors, Electronics, Optics and Precision Instruments, Silicates, and Metallurgy) and at least six universities (Beijing, Qinghua, Fudan, Nanjing, Zhongshan, and Kiaotong), all of which have some sort of research or development program on lasers. Such a strong emphasis on lasers can be explained perhaps by the Chinese belief that the world's future lies with lasers, computers, and electronics, which share the common foundation of semiconductor technology, largely silicon based. This particular view may be too simplistic to be true, but it does seem to explain a number of puzzles. The following paragraphs discuss a few instances of laser development, which is, not surprisingly, in the same mold as in the West.

Solid State Lasers

Neodymium-Glass and Neodymium-Yttrium/Aluminum/Garnet Lasers—The Institute of Optics and Precision Instruments has the most advanced laser technology and instrumentation in China. A neodymium-glass laser system with eight glass rod amplifiers and two Faraday isolators has been built. In fabricating the glass, ceramic crucibles were used to avoid platinum inclusions. The manufacture of good quality glass was up to the world standard. In this neodymium-glass laser system, an electro-optical Q-switch was used instead of the usual saturable dye Q-switch, thus marking a new technique.

The Institute grew neodymium-yttrium/aluminum/garnet crystals of high quality by means of an ingenious technique for eliminating the "coring" effect. A neodymium-yttrium/aluminum/garnet laser was used with a digital readout meter to demonstrate range-finding at the Shanghai Industrial Exhibition.[27] The crystals were also employed in a 20-megawatt oscillator amplifier system to generate the fourth harmonic at 264 nanometers. Such radiation has the scientific merit of being useful for the spontaneous parametric down-conversion of visible light in an ammonium dihydrogen phosphate crystal. A laboratory demonstration was staged for a visiting American delegation of solid-state physicists who watched the generation of blue and red light.[28]

Injection Lasers—Research on injection lasers has been going on for some time at the Institute of Optics and Precision Instruments, the Institute of Physics, the Institute of Semiconductors, and Beijing University. The semiconductor material used is almost always gallium arsenide in the form of gallium-aluminum arsenide, a double heterojunction type. The active lasing region is typically p-type, silicon-doped gallium arsenide having a concentration of 10^{17} carriers per cubic centimeter. Many studies have been made on the lasing action relative to a large number of physical and thermal controlling parameters, including the problem of degradation, which has bothered the Chinese workers as much as it has the American researchers.[27]

It was a great puzzle to the American delegation why the Chinese have put so much emphasis on injection lasers, since the application of such lasers is usually connected with integrated optics and optical communication. At the time of its visit in 1975, the delegation saw no sign of any Chinese work on optical fibers and other related activities.[27] But during a later visit to China in 1980 by G. B. Lubkin, senior editor of *Physics Today*, and during my own visit in the same year, there was evidence that the Chinese are quite advanced in optics techniques and technology. (The Vice-Director of the Institute of Optics and Precision Instruments told Lubkin that "his institute would gladly swap Chinese know-how in advanced optics for American electronic techniques."[25])

Although I would not say that optical technology in China is more advanced (in fact, it may be less) than in the United States, it is still true that Chinese research in laser optics is quite vigorous. The wide areas covered by the Chinese in this field include nonlinear optics with lasers, electro-optic materials, radiation sources and devices, crystal growth of high-quality optical materials (including the use of molecular beam epitaxy), four-wave mixing for two-phase conjugation, work on three-dimensional storage of optical information in chalcogenide glass, and the use of a high-quality six-beam laser for thermonuclear fusion.[25]

Dye Lasers

Dye lasers are apparently not common in China, possibly because not too many native dyes are known to be suitable for laser action or saturable absorbers. Also, such dyes have not been imported from foreign countries.[28] However, Fudan and Qinghua Universities are known to have dye lasers in operation. They both used rhodamine 6G as the dye, a nitrogen laser as the pump, and a homemade grating for the tuning. Yet the instrumentation is not particularly noteworthy at either university.

Gas Lasers

There are many helium-neon gas lasers in the country; Qinghua University alone used to produce several hundred per year. As in other places, they are generally for alignment, holography, and laboratory use.

Argon-ion lasers are not readily available in China, unlike their common appearance in most laser laboratories in the United States. Such lasers are so useful that Chinese research laboratories should be encouraged to import them from abroad if necessary.

Beijing University has a cadmium-ion laser at 441.6 nanometers. It was used to detect nitric oxide in the atmosphere by observing the fluorescence at 650 nanometers from dissociation products of nitric oxide. Qinghua University has a helium-cadmium hollow-cathode laser. Discharge in the helium gas gives rise to positive helium ions that, when reacting with cadmium vapor from a heated oven, result in helium and an excited state of positive cadmium ions. Five of the emission lines produce three colors (blue, green, and red), suitable for color photography at a good power level (40 nanowatts).

There are many carbon dioxide lasers in China. In 1975, Beijing University was said to be constructing a CW carbon dioxide laser designed for an output between 10 and 50 watts, and the Institute of Optics and Precision Instruments was said to have a CW carbon dioxide laser with an output of 200 watts. At the same Institute in 1979, Gloria Lubkin saw a demonstration of a surprisingly powerful 10-gigawatt carbon dioxide laser (probably a very short pulse) by a staff member, Chi Yingshih.[25]

SPACE

Space science is an area of development initiated by the Soviet Union's launching of Sputnik, but the field was quickly picked up and dominated by the spectacular American moon landing and launching of unmanned space vehicles for close observation of planets and their moons in the solar system.

Space science is important for China's Modernization both in the civilian sector and in the realm of national defense. Talking only about the civilian sector, man-made earth satellites are very useful for the remote sensing of land and sea features that are important for surveying natural resources and for agricultural, meteorological, and geological purposes, not to mention their great value for telecommunications.

It is a tribute to the ingenuity of Chinese scientists that they are able to utilize poor-man's technology in launching 13 unmanned space satellites, 8 of which were successful and 5 failed. Of the eight successful ones, two remain in orbit but have lost power for communication.

It came as a great surprise to the world that the Chinese spacecraft launched in January 1978 weighed 1.9 metric tons and was successfully recovered on earth. It can safely be assumed that the Chinese have developed long-distance tracking and telemetering techniques as well as the art of launching and recovering very heavy space vehicles. There are unverified reports that the Chinese are using tracking stations in Zanzibar and Sri Lanka. Moreover, several oceanographic research ships of the Xiang Yang Hong class appear to be suitably equipped for satellite tracking. For all these reasons, interested observers of world space technology speculate that China has the requisite capabilities to launch its first manned spaceflight.[29]

Since 1972, China has been using the International Telecommunications Satellite (INTELSAT) and operates 23 circuits, mostly for international communications. Also in 1977, China formally signed an agreement to become the 98th member of the INTELSAT organization.[29]

There is now a signed agreement between the United States and Chinese governments for the Chinese to purchase a ground station from the United States that will be suitable for receiving signals that LANDSAT will transmit over China. All the satellite remote-sensing information will be shared between the two countries.[30]

HIGH-ENERGY PHYSICS

Among the eight spheres of China's Modernization Program, high-energy physics is the most peripheral to the central theme of the new policy. There have been quite a few observers, both inside and outside China, who sense an element of incoherence in the entire program. However, I am among those who see its meritorious side. Even though the announced policy is meant principally to be short range in nature—concentrating on things that are most immediate and directly applicable—one would think it must be followed by a long-range policy, without a sharp cutoff between the two. The long-range program must place great importance on the advancement of basic sciences. If so, high-energy physics is undoubtedly a leading candidate among the basic sciences for development.

Following are short descriptions of some activities in high-energy physics in China.

Cosmic Ray Research

In 1965, a cosmic ray station was established on a mountain top, 3220 meters above sea level, at Dongchuan, near Kunming, in Yunnan Province. The station is equipped with layers of cloud chambers, under a strong magnetic field, and layers of Geiger-Müller counters. In 1972, a very rare but extremely interesting shower event was detected with an equivalent mass of 10 gigaelectronvolts, but a similar event has not been observed since.[31]

The Alternating Gradient Beijing Proton Synchrotron (BPS)

The BPS proton accelerator, located near the Ming Tombs near Beijing, was announced in 1978 and was scheduled to be completed in 1982, but was later postponed to 1985. The original design called for a preinjection of H^- ions, which are later accelerated in a linear accelerator to 200 megaelectronvolts and still later are injected into the main ring, where the protons, being converted from H^-, are accelerated to 50 gigaelectronvolts.[31]

In June 1979, former Fermilab Director Robert Wilson (a personal friend of mine) "took off his coat" and helped to redesign the accelerator, thereby receiving very warm appreciation from the BPS scientists and the leadership of the Science and Technology Commission.[25] Unfortunately, in 1980 the Chinese government had to reassess its entire economic plan and reluctantly decided on a nationwide retrenchment, which included cutting down the size of the BPS accelerator.

Heavy Ion Synchrotron

This is the principal project of the Institute of Modern Physics, Lanzhou, Gansu Province. The institute director is Yang Chengzhong, a well-known nuclear physicist. I visited the Institute in October 1978. It has been doing heavy-ion research work since 1973. In the first phase of operation, perhaps in 1985, Yang expects to produce heavy ions from carbon to xenon. In the more ambitious second phase, which may be attempted sometime after 1985, Yang expects to produce heavy ions of uranium and accelerate them to 10 megaelectronvolts in a "separated sector cyclotron." Under these conditions he hopes to do some very exciting nuclear transfer reactions and high-temperature thermonuclear fusion experiments.[25]

Controlled Thermonuclear Fusion Research

This research is being done at the Southwestern Physics Institute in Leshan, Sichuan Province. I visited the Institute in September 1980. The director and associate director are my former students, Li Zhengwu and Sun Xiang. Being located in the Chinese interior, the Institute has not been visited by many foreign scientists, except for a group of Japanese in 1977. There are two principal parts to their work, one consisting of magnetic mirror confinement of the plasma (the magnetic field supplied by superconducting coils) and the other consisting of four different sizes of Tokomak machines. The magnetic mirror setup has already been completed. The small, medium, and large sizes of the Tokomak (ranging from approximately 20 to 50 centimeters in radius) were also set up, while the largest Tokomak (radius probably 102 centimeters) is being assembled in northeast China. The principal energy input is by the usual ohmic heatup, whereas the additional energy input comes either from low-frequency field excitation or high-velocity neutralized atoms.

While the work of the Institute toward thermonuclear fusion is steadily progressing, its accomplishment falls very far below the advanced research being conducted in the West.

Synchrotron Radiation Source

It is common knowledge that when an electron is accelerated it must lose energy in the form of radiation. The most common example is that of an electron executing a cyclotron motion around a static magnetic field. This is known as electron synchrotron radiation. In recent years, this highly collimated and polarized radiation has been used as a convenient and powerful source for many physical, chemical, and biological studies all over the world, whereas not long before, synchrotron radiation had been considered a waste.

The Chinese University of Science and Technology at Hefei, Anhui Province, has been establishing a national center of synchrotron radiation for all qualified users.[31] The University has considerable experience in building and using electron linear accelerators and is planning to inject 400 megavolt electrons into a synchrotron that will further accelerate the electrons to 800 megaelectronvolts. We do not know whether the design of this equipment has been completed. In all probability, it will furnish many ports from each of which synchrotron radiation can be led to the user's experimental setup, as is done in many other installations. Since such a source is both powerful in intensity and tunable in wavelength from vacuum ultraviolet to hard X rays, there is hardly any limit to the kind of experiment that can be performed with it.

GENETIC ENGINEERING

Contemporary China has made some concrete progress in the realm of plant and animal genetics in the classical fashion. Much attention and research have been given to the improvement of plant and animal breeding.

Under the new Science Policy, China is looking forward to becoming competitive with worldwide activities in genetic engineering. Since I am a complete layman in this field and totally unqualified to assess the prospect that China will reach the prescribed goal, I can only quote H. M. Temin,[32] a leading authority on cell biology and a Nobel Laureate, who traveled to China in 1977: "I see little chance of the rapid progress in Genetic Engineering anticipated by Vice-Premier Fang Yi. Whole fields will have to be created; supplies of sophisticated reagents and equipment, especially radionuclides, established; and a cadre of scientists trained." Temin feels "a community rich in basic scientists is needed as a basis for successful applied science." I definitely share Temin's viewpoint not only for this particular field but for all sciences in general (in a long-range consideration).

EPILOGUE

I have presented a picture of the present state of China's science and technology relative to the priorities of Modernization announced by the new Science Policy. The picture is partly drawn from my personal impressions and partly from views expressed by many professional Western observers. There is no doubt that Chinese scientists have done extremely well in following the pattern of development initiated by their foreign counterparts, mainly in the field of applied science and technology. But the gap between Chinese science and technology and those of advanced nations continues to be 5 to 15 or 20 years, depending on the field. There is no indication that the gap will be reduced very greatly before 1985.

The net result of the foregoing discussion is that China, given political stability, will certainly be continually modernized but will hardly be able to catch up in an all areas with the advanced nations in 1985 or even in 2000, unless something drastic happens.

I think there are at least three all-important factors that may help to put China on a par with the advanced nations in the world:

1. China must revise its educational system so that there will be a constant level of 800,000 to 1,000,000 professional scientific researchers of good to high quality. The present Chinese educational system is still largely a carbon copy of that of the Soviet Union in the 1950's, wherein the students are so narrowly and rigidly trained that they only fit as cogs of a big machine.

2. China's population must attain the state of nearly zero growth. This is admittedly very difficult to carry out, particularly in rural areas. But progress in China is impossible with too large a population.

3. China must increasingly emphasize basic science (both experimental and theoretical) so that she can develop her science and technology independently, while keeping an open exchange of information between nations and people.

REFERENCES and NOTES

[1] Expanded from a talk delivered at the Science in China Symposium, National Institutes of Health, 20 May 1981. The principal reference for this article is the book *Science in Contemporary China* (cited below as *SCC*), edited by Leo A. Orleans, published by the Stanford University Press (1980). Each individual reference from this book is denoted by the author's name and the page numbers in the book. Each of the other references, not from this book, is individually listed in our usual style. The source material is mainly adopted, but, in a few instances, is modified by the author's personal perception of the state of affairs in China (in the absence of any official information).

[2] Source for Fig. 1: *Science and Technology in the People's Republic of China,* Organization for Economic Cooperation and Development, Paris, pp. 72-73 (1977).

[3] Excerpts from Fang Yi's speech at the National Science Conference, March 18, 1978: "Outline National Plan for the Development of Science and Technology (1978-85); Relevant Policies and Measures," *SCC*, p. 546.

[4] R. L. Metcalf and A. Kelman, *SCC*, pp. 315-316.

[5] T. C. Tso, "Strategy for Agricultural Modernization in China," private communication.

[6] L. A. Orleans, *SCC*, p. 375.

[7] J. R. Harlan, *SCC*, p. 295.

[8] R. L. Metcalf and A. Kelman, *SCC*, p. 313.

[9] T. B. Wiens, *SCC*, pp. 345 and 349.

[10] V. Smil, *SCC*, pp. 407, 408, and 410.

[11] V. Smil, *SCC*, p. 414.

[12] Well-known information.

[13] V. Smil, *SCC*, p. 418.

[14] Private and newspaper information.

[15] V. Smil, *SCC*, p. 407.

[16] V. Smil, *SCC*, p. 424 (also, on display at the Shanghai Industrial Exhibition).

[17] Listed in all handbooks and encyclopedias I have seen.

[18] Described and illustrated in detail in the *China Daily News* (in Chinese), June 24, 1981.

[19] Chang-lin Tien, *SCC*, p. 397.

[20] K. P. Wang, "The People's Republic of China: a New Industrial Power with a Strong Mineral Base," U.S. Department of the Interior, U.S. Government Printing Office, Washington, D. C., p. 72.

[21] J. D. Baldesschwieler, *SCC*, pp. 127-128.

[22] B. O. Szuprowicz, *SCC*, p. 439.

[23] G. B. Lubkin reported in *Phys. Today,* June 1980 (on solid-state physics in China), that Wu Tzu-liang of the Institute of Metallurgy told her a speed of 5 million operations per second was expected in 1978 for the fastest computer in China.

[24] B. O. Szuprowicz, *SCC*, pp. 437-442, 451-456.

[25] G. B. Lubkin, "Physics Today in China," *Phys. Today*, p. 36 (March 1980).

[26] N. Bloembergen, *SCC*, p. 100. Also see Fig. 7.

[27] A. Fitzgerald and C. P. Slichter, eds., "Solid State Physics in the People's Republic of China," National Academy of Sciences, Washington, D. C., pp. 54-55 (1976).

[28] N. Bloembergen, *SCC*, pp. 99 and 100.

[29] B. O. Szuprowicz, *SCC*, pp. 442, 445, and 446.

[30] Private communication from a Chinese official who did not want to be identified.

[31] L. C. L. Yuan, *SCC*, pp. 114-118.

[32] H. M. Temin, *SCC*, pp. 255-266.