Vol. 1, No. 2 January 1984

FUSION ASIA

SCIENCE • TECHNOLOGY • ENERGY • ECONOMICS

INSIDE: THE PROMISE OF BIOTECHNOLOGY

A 50-Year Perspective

Asia Can Lead World Economic Revival

Mm o(.

Vol. 1, No. 2 January 1984

FUSION ASIA

FUSION ASIA is published quarterly and dedicated to providing accurate and comprehensive information on advanced energy technologies and policies. FUSION ASIA is committed to the scientific and technological advancement of all developing nations. FUSION ASIA coverage of the frontiers of science focuses on the self-developing qualities of the physical universe in such areas as plasma physics—the basis for fusion power—as well as biology and biotechnology, space science, laser physics, solid state physics, cryogenics, and includes studies of the historical development of science and technology.

The views of the Fusion Asia Society are stated in the editorials. Opinions expressed in articles are not necessarily those of the Fusion Asia Society's directors or of the journal's Advisory Board members.

FUSION ASIA is printed and published by Ramtanu Maitra for Fusion Asia Society at Parul Printers, NOIDA. (U.P.)

Registered Office : 39, Okhla Industrial Complex, Scheme III Phase II, New Delhi-110020

Editorial : C-9 Nizamuddin East New Delhi-110013

Features

News

Departments

Editorial

Putting the Energy Crisis into Perspective

The Twelfth World Energy Congress held in September in India presented a contrast to previous sessions of the nearly sixty-year-old Congress, not merely because it was hosted for the first time by a developing nation. The energy experts from many countries assembled in New Delhi put into proper perspective the nature of the energy crisis, and the limitations of the much-touted alternate energy sources in particular.

The speakers, mostly representing utilities and industry, made it clear to the 3000 delegates—including twenty or more ministers, mostly from developing countries—that until such time as thermonuclear fusion becomes available, electricity generation via nuclear fission, hydropower and fossil fuel will have to carry the brunt of energy demand. Solar, wind, geothermal and the rest might be transitionally important in particular, limited circumstances but will remain minor and strictly non-commercial energy sources overall. It is a welcome relief that a rudimentary understanding of physics did finally prevail after several years of speculation on the "alternates."

This conclusion was presented from a number of standpoints in a host of quality presentations. There were more than 160 papers prepared by authors from some 50 countries. Their contents were discussed at a series of technical sessions, round tables, working group meetings and "poster sessions" running concurrently throughout the week. Representation was broad, though South and Southeast Asian ranks were thin. Since the delegates were overwhelmingly professionals, businessmen and energy officials the environmentalist litany one has come to expect at a conference on energy was refreshing by its absence.

Discussion on the prospects for solar power, the brightest star in the "alternate" galaxy, centered on capital costs and basic logistics. M. Durand, French delegate and Assistant Secretary General in NATO's Scientific Division, outlined clearly why an energy programme based on solar power development would be suicidal for developing nations. Speaking from personal experience of intimate contact with photovoltaics manufacturers, Durand said that the cost of electricity generation via solar cannot be brought below three times the capital cost of nuclear power generation. He also pointed out that to build a 1000 MW solar thermal power plant requires 50 square kilometres of land area, whereas a nuclear power plant of the same capacity takes up a mere 0.25 square kilometres. For developing nations with large populations, few cities, and a large land area required for industrialisation and agricultural development, it is not a trivial point.

> ***The world does not face an energy crisis, but rather an economic crisis that has been a major barrier to energy development programmes of most nations.***
>
> —WEC Sec. Gen. Eric Ruttley
> Concluding 12th Congress

Besides spotlighting the shortcomings of the low energy flux density alternates, there was serious discussion of the necessity of nuclear power development. France, India and the U.S. stood out here. American reports emphasised the excellent record of nuclear power with regard to competitive costs, efficiency and pollution. The French were not only bragging about their excellent nuclear-based electricity development programme, a model of "self-reliance." They were also heralding the age of the fast breeder reactor, urging those who have developed nuclear fuel cycles for their first generation reactors to move quickly for breeder development. In this the French were in league with the Indians, who have long since chalked out their breeder programme in detail.

This is a welcome initiative for "energy independence." Both France and India offer important models to developing nations. Our international news section features a detailed report on the construction of the 1200 MWe SuperPhenix fast breeder reactor in France, and we are looking forward to reporting on the early startup of India's 15 MW test breeder reactor.

The present constraints and enormous potentials for nuclear energy in the developing sector was discussed at length. International Atomic Energy Agency (IAEA) officials pointed first to the fact that while most developing nations have small and fragmented transmission grids, nuclear power plants below 600 MWe capacity are not generally available. According to IAEA there are some 15 countries, all developing, which could use units in the 200 to 600 MWe range—a clear indication of the potential market for small reactors, provided they were economically viable and available without political preconditions.

On the former point there were some interesting discussions. H. Hirschmann, Executive Vice President of the West German reactor manufacturer Kraftwerke Union, described the ongoing work in this field, and demonstrated that the small reactors do compare favorably with coal and oil-based plants.

The big question remained, however, as to how the logjam created by the developed nations to prevent nuclear power development in the developing sector can be overcome. **An obvious and promising suggestion came from the floor:regional cooperation among the developing nations themselves could overcome the difficulties presently faced by small nations in adopting nuclear energy technology. The South Asia region is a prime example. Since India has developed the entire nuclear fuel cycle, it would be entirely appropriate to India's leadership of the region to help the neighbouring nations develop nuclear power for peaceful use.**

We expect this debate to rage and look forward to early steps toward such regional cooperation.

On the need for electrification for industrialisation and economic advance, a few excellent papers were presented. The most far-reaching was undoubtedly that of Fremont Felix, a consultant with the American firm Gibbs and Hill. Felix stressed the need to dispense with the practice of equating electricity use and raw energy consumption.

Especially thought-provoking was Felix's analysis of the way in which electrification fosters economic development, bringing forth more and more sophisticated products and extending labour resources. Electricity promoted the shift toward small manufacturing units, he said, encouraging decentralisation—an important issue in developing nations with large rural populations. After all, as Felix told an Indian reporter, "What can be more decentralised than a wall plug?"

Happily, fusion was on the agenda at this conference, albeit sandwiched in among the "alternates." Dr. R.S. Pease, Fusion Programme Director for the UK Atomic Energy Authority and Chairman of the IAEA's International Fusion Research Council, gave a thorough and lively status report on fusion development. He emphasised that fusion is one of the major areas of international collaboration today with significant long-range impact.

While these and other papers inspired delegates, and gave them ideas as to the direction in which to proceed, a survey presented by the World Energy Congress authorities was void of imagination if not downright counterproductive. Based on linear extrapolations of historical data, without paying any attention to the increased efficiency caused by *advancing* technologies and the new and better technologies which will emerge in the near future, the survey concluded that by the year 2020 sub-Saharan countries will rely on wood to meet their fuel needs, the South Asian nations would be consuming animal wastes as their main energy source, and the Latin American nations would be totally dependent on hydro-electric power.

The report is absurb and misleading. Inasmuch as this type of forecast, once put into the policymaking pipeline of individual nations, becomes a basis for making energy policy decisions, the exercise is irresponsible. The simple fact of the matter is that the developing nations are desperately trying to increase their energy production. It is no secret that they are looking for capital and advanced technology, both of which they lack, to do it. *If these requirements are not met,* either by the developed nations or through regional cooperation within the developing sector, then these countries will not only be dependent on dung and firewood but their very existence as sovereign nations will be in jeopardy. The pretention that the poor and developing nations of the world can survive in 2020 by depending on fuelwood and animal wastes is a misanthropic hoax. ■

Felicitations to Dr. Chandrasekhar!

Our felicitations to Dr. Subrahmanyan Chandrasekhar for winning the 1983 Nobel prize for physics. Professor Chandrasekhar, who has been associated with the University of Chicago since 1937, was belatedly honoured for his work on the nature and behaviour of dying stars. While at Cambridge in the thirties Dr. Chandrasekhar presented his theory to the Royal Astrophysical Society, startling the leading astrophysicists of the day.

At any given time a star loses the ability to balance the pressure and gravitational attraction at its periphery by simply adjusting its radius unless the core happens to remain below a certain limiting mass, Dr. Chandrasekhar showed. The critical limit, known as Chandrasekhar's Limit, is 1.44 times the mass of the Sun. It must not be exceeded if a star is to survive as a White Dwarf. If the mass of the collapsing star is greater than the limiting mass, Dr. Chandrasekhar noted, the collapse becomes a certainty since the comprehensive gravitational force for that large a mass becomes so great that the free electrons at a high energy level collide with the nuclei to become neutrons. As the free electrons disappear, the outward radiation pressure which was balancing the gravitational force reduces sharply and the star eventually collapses.

Dr. Chandrasekhar's work has since been firmly established and his mathematical work concerning the study of stellar structure is now extensively used in space research, remote sensing and astronomy. But Dr. Chandrasekhar has not confined himself only to this part of astrophysics, and has involved himself in doing pioneering work in various related fields such as the properties of spiral arm galaxies, magneto hydrodynamics and general relativity. He is now concentrating on plasma physics.

"Thinking about problems" is the way Dr. Chandrasekhar describes the life work which gives him great personal pleasure and which has given mankind important new knowledge. He shared some of his thoughts about science and the beauty of creative discovery with an *Indian journalist.* "The reason for pursuing pure science cannot be measured in terms of needs, though needs are relevant and important and in many instances have the first priority. But to say that human needs have the first priority is not to say that the long-range needs of the human spirit can be ignored" he said. "When one begins to study an area in physics or another field of pure research that is confused and full of mistakes, and then through one's study the subject becomes clear and whole, it assumes a perspective and beauty."

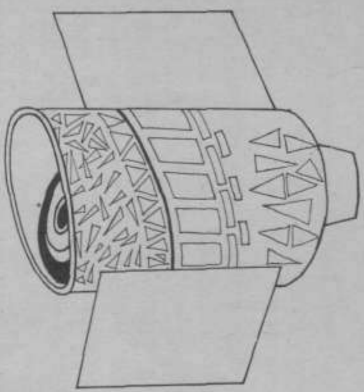
Only recently Dr. Chandrasekhar's latest book, on black holes, the product of a nine-year study which Chandrasekhar himself considers to be his "best" work yet, was published. At the age of 73 Dr. Chandrasekhar is an inspiration to all of us. We wish him a long life.

News Briefs

IRAS SURPRISES THE SCIENTISTS

The Infrared Astronomy Satellite (IRAS), launched on 25 January by the United States National Aeronautics and Space Administration, has reported a number of significant discoveries which have puzzled scientists. The series of new findings started with the IRAS detecting five new comets and a "miniplanet" only 1.2 miles in diameter circling within the orbit of Mercury. The most spectacular discoveries, which were reported recently by the IRAS, include a shell of dusty material around Vega and at last 50 new stars with possible planetary systems. IRAS has also found a giant husk of material around Betalguese, a red supergiant star in the Orion constellation.

The latest findings, sent in early November, include a view revealing swirling "cirrus clouds" of dust and a distinct dust ring beyond the orbit of Mars. The ring, which resembles a triple structure, includes a thick central ring flanked on either side by thin rings. The rings are tilted at about nine degrees to the ecliptic, the central plane of the solar system.



The IRAS, a sketch.

The infrared radiation that IRAS is measuring from the far-away galaxies is registered as heat in the telescope. To make sure that any heat they are measuring is the heat of the galaxies, and not inside the telescope, the telescope is kept at about 2 degrees above absolute zero. The satellite carries 154 pounds of liquid helium, enough to keep the IRAS cool for ten months. IRAS has so far identified more than 180,000 small dusty sources, most of which are too cool to radiate light and to be visible from Earth.

Scientists have been totally intrigued by the IRAS' findings. According to scientists, it will take two to three years to analyse the "photographs" IRAS has sent. But one thing that the scientists have acknowledged is that the Universe appears to be far more "dusty" than had earlier been assumed. Since such dust clouds mark the beginning of new stars, the rate of star formation in the galaxies is much greater than the scientists had earlier thought. This also suggests that the birth of stars like the Sun is a relatively more common phenomenon in the galaxy.

CHINA JOINS THE IAEA

Last October the People's Republic of China (PRC) formally became a member of the International Atomic Energy Agency (IAEA) at the Agency's Annual General Conference in Vienna. Since China is now actively pursuing development of nuclear power for energy generation, its admission into the IAEA has been welcomed by all. One of the major roles of the IAEA is to impose nonproliferation safeguards on the reactors of member nations.

The immediate beneficiaries of China's move will be those reactor manufacturers in the West who were not previously allowed to supply reactors to China because the country was not a member of the IAEA. In early 1983 Framatome, the French reactor manufacturer, was reportedly the front-runner to receive an order for two 900 MWe Pressurised Water Reactors scheduled to be installed at Xian Dakeng in China.

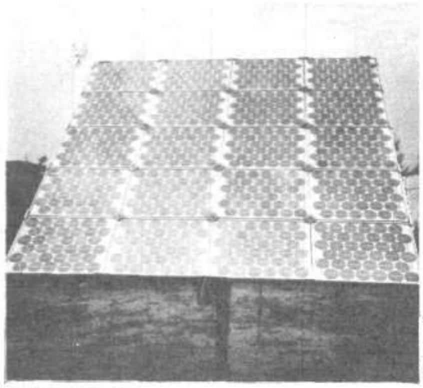
During the summer, prior to IAEA Director General Hans Blix's visit to China, negotiations between the United States and China on nuclear technology transfer were stepped up. China's admission to the IAEA will now free Westinghouse, Inc., the American reactor manufacturer which had also been negotiating for the supply of the Xian Dakeng reactors, albeit through a British company, to enter the bidding for the reactors as well as the turbines in its turbines in its own right.

ANOTHER SETBACK FOR SOLAR ENERGY

The lack of future prospects for solar energy as a viable commercial energy source is causing financial problem to its promoters. RCA Corporation of the United States, the leading researchers of photovoltaics in the world, have decided to sell their technology lock, stock and barrel to a Maryland-based firm and get out of the solar cell business completely. RCA reportedly decided about a year and a half ago that it would not risk the large amounts of capital, estimated to be as high as $100 million, needed to pursue photovoltaics development. The investment decision centered on plans to set up production facilities for making amorphous silicon cells.

RCA's decision to get out of photovoltaics is a reflection of what the solar cell experts are now discussing openly. At the last World Energy Conference held in New Delhi in September, experts from around the world made it clear that they do not foresee any miracle in overcoming the problems that are hounding solar energy development.

Meanwhile, the multinational oil companies, who wield a lot of political and economic power, are funding solar energy development heavily. The purpose is to keep nuclear power out so that oil continues to be the chief industrial fuel. Standard Oil of Ohio (SOHIO) and Standard Oil of Indiana are currently helping to bankroll amorphous silicon photovoltaic cell manufacturing in the United States.



PIB, India

Solar panels.

INDIA INSTALLS LARGEST TELESCOPE IN ASIA

In January 1984 Indian scientists will complete installation of the largest optical telescope in Asia. The telescope, designed and fabricated by the scientists of the Indian Institute of Astrophysics in Bangalore, will be mounted at the Kavalur Observatory in Tamil Nadu.

Dr. J.C. Bhattacharya, Director of the Indian Institute of Astrophysics and a noted astrophysicist, has said that the telescope will help scientists to obtain valuable data from the galaxies and provide a better understanding of the stellar origins and skies. India will be the first developing country to embark on such a venture.

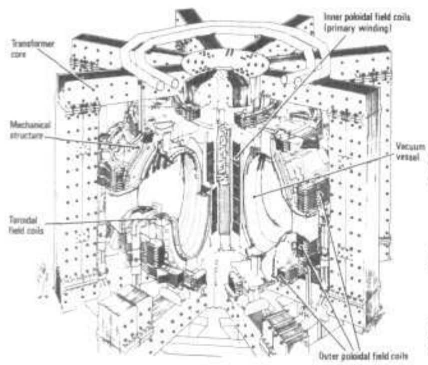
The new telescope has a mirror that is 2.34 metres in diameter and weighs 3.5 tons. The entire telescope arrangement weighs close to 100 tons. The mirror also possesses a high level of accuracy: no two points in the mirror have a level difference of more than 0.01 micron in the theoretical parabola. The telescope will be supported by a computer for storing and analysing data. The computer will also control the telescope for automatically pointing it to a given star or galaxy.

The Kavalur Observatory has been picked for installation of the $5 million telescope because at Kavalur the telescope can operate in a latitude range where few large telescopes are now in operation. It is also suited for the study of the relatively unexplored southern Milky Way.

JET REACHES A NEW MILESTONE

Joint European Torus (JET), the largest project in the European nuclear fusion programme, produced discharge currents of one million, three hundred thousand amperes on 27 October, with a duration of more than one second. This has been considered by the scientists as an early milestone in the drive towards the achievement of full performance parameters (four million eight hundred thousand amperes).

As the JET project continues the plasma current will gradually be increased to 4.8 MA and additional heating equipment (25 MW) will be added to the machine with the aim of raising the hydrogen plasma to a temperature of about 50 million degrees for periods of about 10 seconds. If this is successful, then towards the end of the project deuterium and tritium gas instead of hydrogen will be introduced into the machine to produce fusion reactions. At that time it is hoped that the self-heating effect will raise the temperature further to the required 100 million degrees centigrade, releasing bursts of high energy neutrons. In a future fusion reactor these neutrons will be the source of heat for producing electricity.



JET Annual Report, 1982

The JET reactor, a schematic.

International News

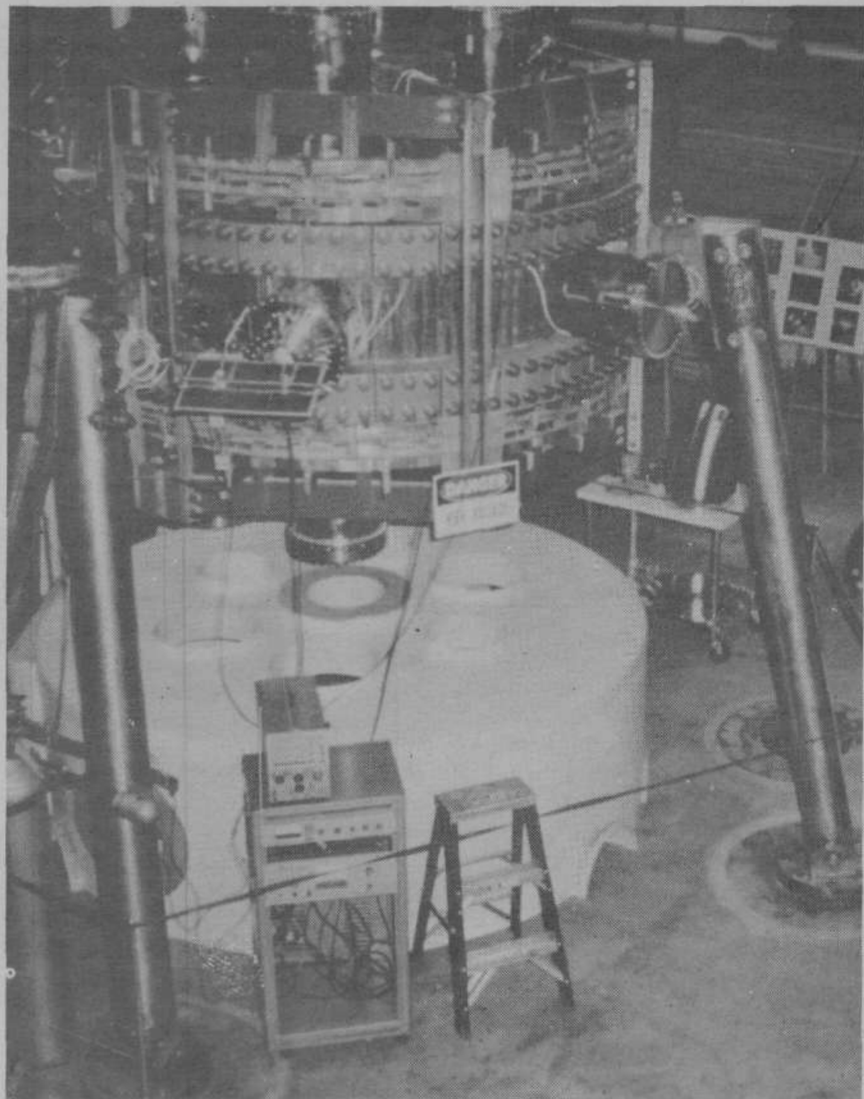
U.S. Program Makes Important Advances In Magnetic and Inertial Confinement

Over the past three months both the low-density, continuous operation magnetic approach to fusion as well as the high-density, pulsed method of inertial confinement have made major progress. These results, reported in recent international fusion meetings, continue the steady, often dramatic, advances in fusion research over the past five years.

At the Los Angeles meeting of the American Physical Society's Plasma Physics Division Nov. 7, Dr. Ronald Parker of the Fusion Center at the Massachusetts Institute of Technology announced that the Alcator C tokamak had approached the confinement parameters needed for energy breakeven in electric power reactors based on magnetic fusion energy. The confinement parameter achieved on Alcator C approached a value of 100 trillion seconds-nuclei per cubic centimeter.

This parameter has long been one of the major goals of the world effort to harness the virtually unlimited energy potentials of nuclear fusion. The other major element needed to demonstrate scientific feasibility of magnetic fusion energy production was attained on the PLT tokamak at the Princeton Plasma Physics Laboratory in 1978, when it was shown that a stably confined magnetic plasma could be heated to more than 80 million degrees Celsius—the temperature needed to ignite nuclear fusion in power reactors.

All previous fusion reactor studies have come in with projected costs 25 to 100 percent greater than fossil and fission. As Nuckolls concludes in his report: "This is a remarkable and exceedingly important result. . . . This low cost economic potential would provide strong commercial incentives to accelerate the pace of fusion development in the near term, and to install a fusion energy system in the long term."


MIT

The Alcator C at MIT recently approached the density-confinement time parameters needed for breakeven, at 100 trillion seconds-nuclei per cubic centimeter.

Although Nuckolls primarily focuses on inertial confinement fusion, the type of fusion that he helped pioneer, he notes that, "These remarks about the economic potential of fusion apply to all of fusion not just inertial fusion." Nuckolls also points out that development of both general approaches to fusion to should be accelerated.

In detailing the scientific prospects for inertial confinement Nuckolls notes the crucial benefits of polarizing fusion hydrogen fuel. This can lead to a threefold decrease in the required laser energy needed to achieve inertial confinement and in developing entirely new approaches to inertial confinement target design. *Fusion* magazine was the first to point out the unique applications of polarized fusion for inertial confinement in the analysis that was published in a special issue in September 1982.

In his economic analysis Nuckolls uses a cost-benefit argument to show that spending a few billion dollars needed to accelerate the development of fusion now, will pay off in the tens of trillions of dollars in 21st century in the world energy market and guarantee the technological preeminence of U.S. industry. Nuckolls concludes that because of this tremendous payoff, the "United States has strong incentive to accelerate fusion research—other nations have similar incentives."

Although the Alcator C reached a temperature of only 16 to 17 million degrees, its achievement of the confinement parameter leaves little doubt that the Princeton Tokamak Fusion Test Reactor (TFTR) and Joint European Tokamak (JET), both of which became operational over the last year, will achieve both the temperature and confinement parameters needed for operation of tokamak magnetic fusion reactors.

The Alcator C reached higher density operation by utilizing pellet injection of hydrogen fuel—fuel ion densities were 2,000 trillion nuclei per cc. With a peak energy confinement time approaching 50 milliseconds (.05 seconds), the Alcator C had essentially reached the goal of the Lawson product, 10^{14} particles per cc per second.

More significantly, the recent experiments on the Alcator C and the TFTR indicate that confinement time is a function of the product of the plasma density and the cube of the plasma column radius. This is far better than what had been predicted by the most optimistic theoretical projections of the 1950s. Furthermore, experiments on Princeton's PLT and PDX and the West German ASDEX tokamak indicate that confinement can indeed improve with increasing temerature.

Also, experiments on the Alcator C and the PLT utilizing microwaves show that tokamaks could be made into what are effectively steady-state devices. Using microwaves, tokamaks can be kept running for up to a day at a time. It was previously feared that pulsed operation inherent in the tokamak would incur serious economic and engineering drawbacks in power plant design.

Fusion's Economic Potential

Dr. John H. Nuckolls, associate director for physics at the Lawrence Livermore National Laboratory's Inertial Confinement Division, presented a new, revolutionary analysis of the economic prospects for nuclear fusion at the European Laser-Matter Interaction Conference held the first week of October in London, England. Using results from recently completed advanced reactor designs, Nuckolls demonstrated that fusion has the ultimate economic potential of generating electricity for half the cost of the currently cheapest methods—nuclear fission and coal.

Nuckolls states: "Relative cost escalation would increase this advantage. Fusion's potential economic advantage derives from two fundamental properties: negligible fuel costs and high quality energy (which makes possible more efficient generation of electricity)."

French SuperPhenix
Largest Fast Reactor Comes On Line

Less than six months from now, France will emerge as the nation with the most advanced nuclear technology. In 1984 the French will start operating the new 1200 MW plant, SuperPhenix at Creys-Malville. SuperPhenix will be the largest prototype fast reactor in the world in operation.

The decision to build a fast reactor plant at Creys-Malville was taken by the Board of NERSA (Centrale Nucleaire a Neutrons Rapides S.A.) on 20 December, 1976. Civil engineering work started in 1977, and in seven years the plant will be completed. While the Clinch River Breeder Reactor in the United States has been under construction for almost a decade and still no final completion date has been pinned down, the French effort can be regarded as satisfactory if not spectacular.

How did France do it? And why are the other advanced nations lagging behind? The answer to both questions can be seen from the current scope of the French programme and its political history.

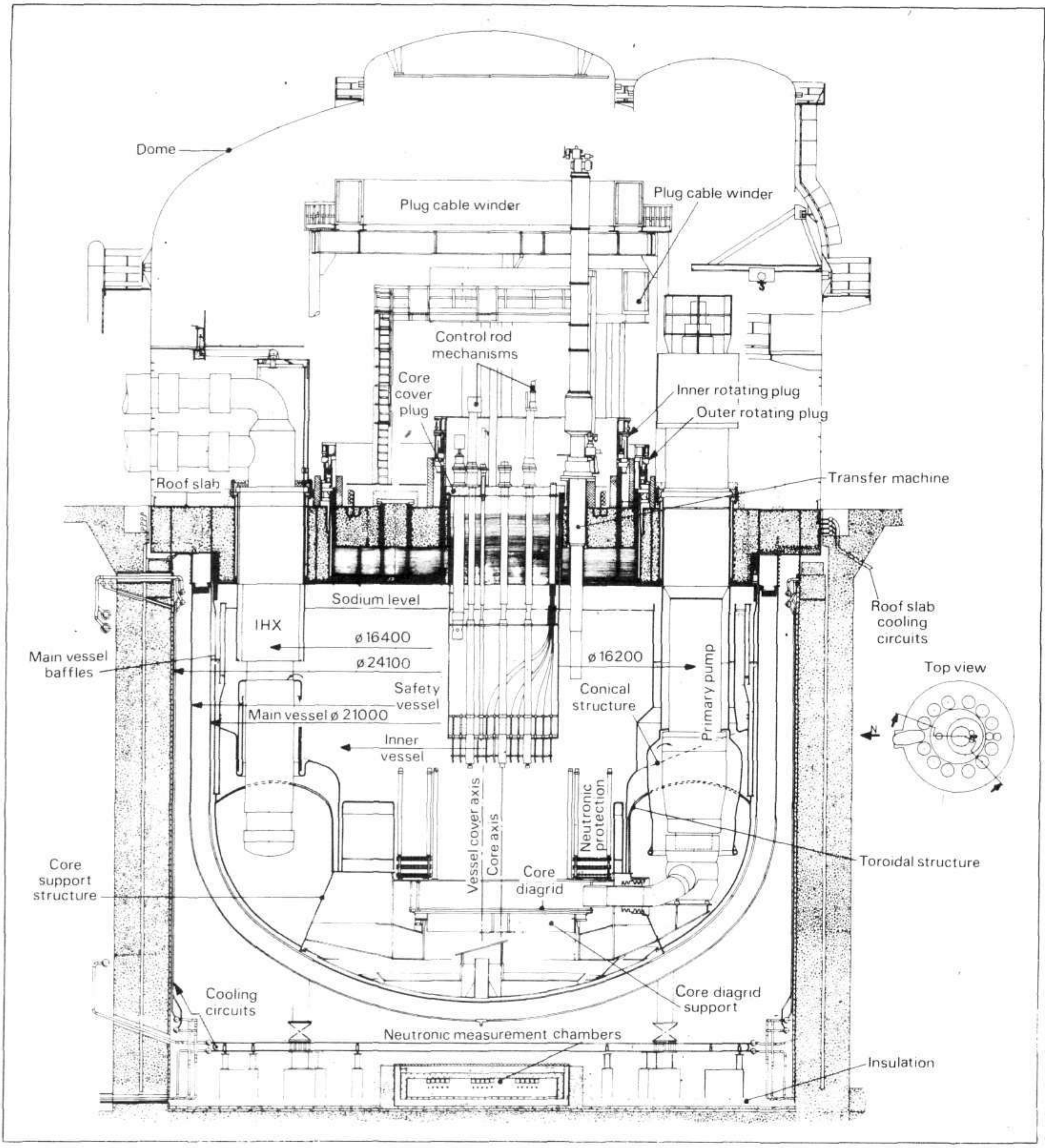
Behind SuperPhenix

In 1953, the French started doing fundamental research work into the physical properties of neutrons initiated at the Saclay and Fontenes-aux-Roses centres.

In 1960, the French Atomic Energy Commission (CEA) established the first test facility for sodium technology at Cadarache. The test facility provided nuclear scientists and engineers the facilities to investigate the special technological features of sodium-cooled fast reactors.

Seven years later, the CEA installed the first experimental reactor, Rapsodie, with a capacity of 40 MW. This experimental reactor (which provided the basic design for the first Indian experimental fast reactor (FBTR), due to be commissioned by the end of this year) has now been under operation for almost sixteen years. It has provided French nuclear engineers a wealth of data regarding performance of the major components of the system, together with a high quality nuclear fuel suitable for large capacity fast reactors.

However the dirigist French approach in developing nuclear energy goes back to the pre-Second World War days when Irene Curie and her husband, Frederic Joliot, joined Marie Curie's laboratory at the Ecole de Physique et de Chimie in Paris. It was their work that laid the foundation of France's rapid development in the field of atomic energy before the war broke out. In 1934, Frederic Joliot and Irene Curie won the Nobel Prize. In his acceptance



Nuclear Engineering International

Arrangement of the main primary circuit components in the SuperPhenix fast reactor.

speech, Joliot predicted the next phase of their discoveries—the fission of uranium nuclei, which took place in 1938-39—and the enormous potential it would unleash for humanity.

CNRS : a Landmark

Joliot-Curie and their circle of collaborators established the Centre National de la Recherche Scientifique (CNRS), a government body whose responsibility was to develop, direct, and coordinate all French scientific work. The establishment of CNRS is considered a landmark for developing scientific work in France. Immediately at the war's end, the de Gaulle provisional government made Joliot director of the CNRS. During his involvement with the CNRS Joliot corresponded with General Charles de Gaulle on the importance of keeping the lead France had attained in the field of atomic energy.

Soon after, de Gaulle made the decision to set up the French Atomic Energy Commission (CEA) with Joliot as director. CEA became the world's first postwar civilian institution dedicated to the development of nuclear technology. Joliot took the opportunity to gather around him virtually all his former scientific collaborators who had returned from the war effort abroad having acquired considerable experience. This experience soon proved to be of immense value: on December 15, 1948, France's first atomic pile, "ZOE", went critical.

The CEA'S role has been increased over the years, but the agency's areas of responsibility are still the three areas originally assigned to it: prospecting, extraction and enrichment of uranium ore, overall planning of the national nuclear industry and research and development. In the late 1950s, the CEA was also assigned responsibilities in the military field, which now include the task of developing nuclear warheads for French atomic weapons as well as the reactors for atomic submarines.

In the case of SuperPhenix, pooling of research and development know-how was made available to the constructors by means of a system license granted by the CEA through the European System Company (SERENA). In March 1977, NERSA placed the order for the turnkey supply of the nuclear boiler for SuperPhenjx with the French firm NOVATOME and the Italian firm NIRA, acting jointly. The contracting parties are entirely responsible for the design, construction and turnkey supply of the boiler.

Complete Nuclear Cycle

During the period leading up to the decision to install fast reactors France had developed a complete nuclear fuel cycle. In 1973 France began building Western Europe's first civilian uranium enrichment plant in Tricastin, setting up a consortium called EURODIF. The EURODIF plant, built at a cost of U.S.$3 billion, drew its technology from France's military uranium enrichment plant at Pierrelatte, which produced its first usable quantities of fissionable U-235

TECHNICAL AND GENERAL CHARACTERISTICS OF THE SUPERPHENIX PLANT

Reactor type	:	Integrated type, sodium-cooled, fast reactor
Nominal thermal capacity of boiler	:	3000 MW
Gross electrical capacity	:	1240 MWe
Fuel composition	:	mixed oxide sintered UO_2-PuO_2
Mass enrichment with Pu 239 equivalent	:	15.12%
Breeding ratio	:	0.183
Maximum burn up rate (planned figure)	:	70,000 - 100,000 MWd/t
No. of fuel assemblies in core	:	364
No. of pins per assembly	:	271
Cladding material	:	stainless steel
Nominal maximum cam temperature	:	620° C
No. of radial blanket assemblies in core	:	233
No. of pins per assembly	:	91
Cladding material	:	stainless steel
Shape of reactor vessel	:	cylindrical with torispherical bottom
Inside diameter	:	21000 mm
Height	:	19500 mm
Metal	:	stainless steel
Heat-transfer fluid in primary loops	:	sodium
Total mass of sodium in primary loops	:	3500 t
Temperature at core inlet	:	395° C
Temperature at core outlet	:	545° C
Heat transfer fluid in secondary loops	:	sodium
Total mass of sodium in secondary loops	:	1500 t
Temperature at outlet from steam generators	:	345° C
Temperature at inlet to steam generators	:	525° C
Temperature of water at inlet to steam generators	:	235° C
Temperature of steam at turbine intake	:	487° C

Courtesy: Bulletin d'Informations Scientifique et Techniques in March 1979. With the completion of the EURODIF plant last year, France is now capable of producing 10.8 million separation work units, or about 25 to 30 percent of the world's capacity.

With the future construction of fast reactors in mind, the French also started building their fuel reprocessing facility. Now France has two reprocessing facilities which can recover 96 percent of the low enriched uranium and one percent of the plutonium from spent fuel. The low enriched uranium can be reused as fuel and plutonium can be used to start up the breeder reactors and fuel them until the new plutonium is bred by the fast reactors.

Following the oil embargo in 1973, France started to move fast with the installation of pressurized water reactors (PWRs). Presently the PWR installations are well under way. At the end of the seventies, nuclear energy accounted for only 11 percent of France's total energy consumption. With 23 reactor units now connected to the grid, the nuclear plants accounted in 1981 for almost 40 percent of French electricity production or nearly 100 Terrawatt hours. By 1990, it is estimated that nuclear power will supply 70 percent of France's total electricity use.

France's long-term energy planning group has recently suggested that two units of plant be ordered per year until the year 2000. They say that at an ordering rate of two units per year the French nuclear industry can be maintained in its present form, although it will still be necessary to reduce the research and development effort and to increase exports.

Energy Independence

But French planners are also concerned about the vulnerability of uranium. In the ten years since the oil embargo was imposed, the French have partially substituted uranium for oil as the energy generating source. The planners are, however, also aware that the PWRs, which use uranium as the feedstock, may cause the same difficulties as those encountered with oil during the past ten years. Oil blackmail, which took the form of supply embargoes, price hikes and so on, was very vivid in their memory when they planned for building fast reactors. Even with proven uranium reserves of 12,000 tons, France has a deficit in relation to her projected nuclear development, which requires reserves or more than 150,000 tons up to the year 2000.

It is the determination to be independent that led France to move toward the fast breeders from the well-established pressurized water reactor technology. In essence, France's nuclear programme serves as a model for the completion of the nuclear fuel cycle—from fuel enrichment, reprocessing and breeding, to storage of waste.

Phenix

In 1974, the 250 MW Phenix fast reactor was commissioned. The entire construction of Phenix, from design board to the tightening of nuts and bolts, took the French less than six years. The performance of Phenix has proven the fact that the French pool-type concept of fast reactor design is a valid one. In this design the complete primary circuit of the reactor is contained within a single vessel, from which only secondary, non-active, sodium in released. This means that loading and maintenance crews are subjected to much lower exposure to radiation than that which is commonly recorded in PWR plants.

Although Phenix was an extremely successful facility, it was not entirely trouble-free. In 1982, the plant was shut down due to a sodium-water contact—the first such incident to occur in eight years of operation. The plant, after proper inspection of the faulty steam generator and replacement of the damaged component, was restarted two months later. But it was a process of learning, and the lesson that the French taught others is the fact that the sodium-water reaction can be contained and the plant can be restarted without a long delay.

In the "pool" type Liquid Metal Fast Breeder Reactors (LMFBRs) not only the core—which is a compact arrangement of fuel assemblies similar to those used in the light-water reactors except that the fuel material is more highly enriched and the cladding is stainless steel rather than Zircaloy—but also a number of other components are contained in the reactor vessel. The vessel is filled with sodium at roughly an atmospheric pressure, in which the core, refueling machines, the primary coolant pump and the intermediate heat exchangers are immersed, so that the entire primary sodium loop is contained in the same vessel. This assembly significantly reduces the amount of external piping.

In essence, the reactor block is comprised of the main vessel and inner structures, the upper closures consisting of the roof slab and the rotating plugs, the safety vessel and the emergency circuit, the control rod mechanisms and the control rods forming the main shutdown system (SAP) and the supplementary shutdown system (SAC), the instrumentation of the reactor block, the dome which forms a containment in the event of leaks of contaminated argon, the reactor block preheating unit and the core cover and the corresponding plug (BCC) which forms part of the upper closures. (See Figure 1 page 8.)

SuperPhenix

The SuperPhenix is such a "pool" type LMFBR. As in all breeder reactors, the core of SuperPhenix will be made a mixture of oxides of plutonium and uranium. Surrounding the core will be a blanket of uranium. Fission will occur primarily in the core region and conversion of plutonium will occur in both regions.

Power generation in both the regions with heavy fissile loading, U-238 and Pu-239, will be quite intense. Sodium, a metal that is liquid over a large range of temperature, is used as the coolant since it can successfully cool the very compact core, with high power density. The basic advantage of using sodium is that it can be used at essentially atmospheric pressure, thereby making design easier. And since sodium can operate at such high temperatures, the sodium-cooled reactor permits higher plant efficiency than the water-cooled reactors can achieve.

In SuperPhenix, as in all LMFBR designs, the sodium that cools the core is not used to raise the steam that drives the turbogenerators.

Instead, there is an intermediate sodium loop which avoids the possibility of releasing radioactive sodium during any steam generator problem. Thus the type of malfunction experienced in the Phenix steam generator in 1982 is impossible. The intermediate heat exchanger will interface between the primary and secondary loops. It will effectively isolate the primary sodium, and thus the sodium-filled reactor, from any water.

Fuel Lifetime

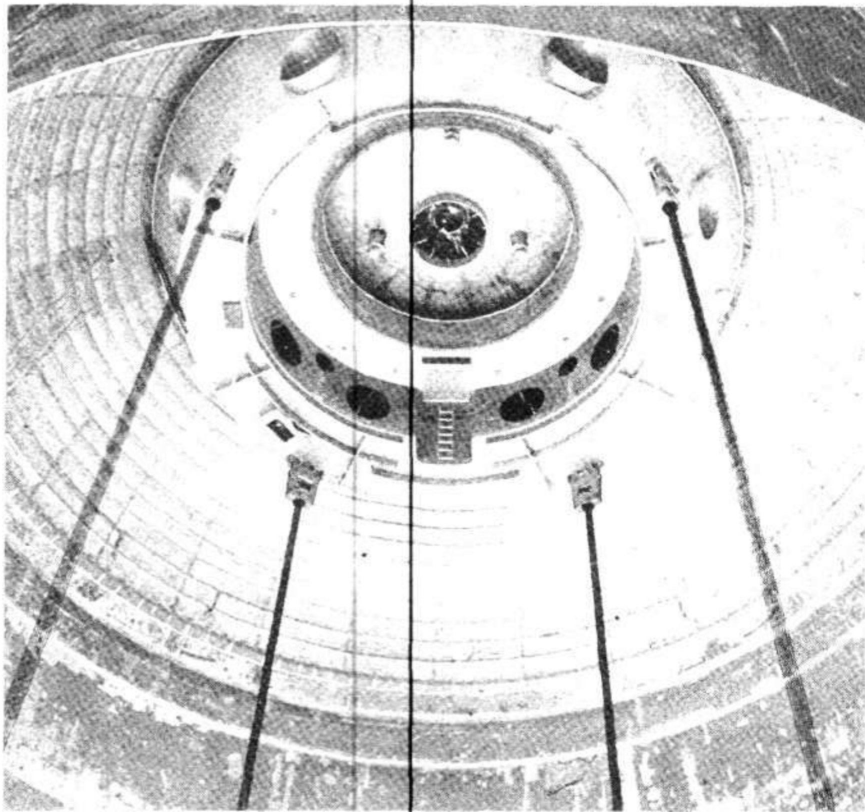
An important question for fast breeders is that of fuel lifetime. In thermal reactors, only a small percentage of the fuel atoms fission before the fuel is removed for storage or reprocessing. In fact, in the case of thermal reactors the fuel "burnup" is only 2 to 3 percent. But the breeder has a fissile loading of more than 15 percent or more, and the power density (and, correspondingly, the per volume rate at which nuclear fission takes place) is much greater than in water-cooled reactors.

For the fuel assemblies to have a sensibly long lifetime in the reactor, the burnup that they can tolerate must be higher, around ten percent. The relatively compact SuperPhenix core will imply a greater neutron flux through the core structure than typically occurs in thermal reactors. SuperPhenix will use uranium with 50 to 60 times the efficiency of conventional nuclear reactors. One kilogram of natural uranium will produce 30,000 kilowatt-hours of energy in a graphite gas reactor, and 45,000 kilowatt-hours in a water-cooled reactor; but the same amount can produce between 1.5 million to 3.0 million kilowatt-hours in a fast breeder.

The French have the advantage of learning about the fast reactors because of their well-planned step-by-step approach to breeder development: the Rapsodie test reactor, leading to Phenix, leading to SuperPhenix. They have also kept up high profile research and development programmes in critical technologies such as steam generators, sodium-water reactions, sodium pumps.

The study of sodium-water reactions was concentrated primarily on the occurrence and evolution of a leak and its effects on other tubes. The research and development programme focussed on developing quick monitoring devices as well as methods for repairing a damaged steam generator and returning it to service. Another interesting study concerning the generation of pressure waves because of the sudden rupture of pipes has also provided the basis for determining the wall thickness for the steam generator's outer shell.

Continuation of the development programme for heat exchangers will remain important for developing more reliable and cheaper assemblies.



Installation of the Superphenix main vessel into the safety vessel at the Creys-Malville site.

Environmentalists Defeated

SuperPhenix construction, however, had its share of environmentalist-terrorist threats.

The June 1979 planned environmentalist armed assault against the fast reactor at Creys-Malville, however, was turned into the environmentalists' Waterloo as the result of active intervention by the French govern- and nuclear industry.

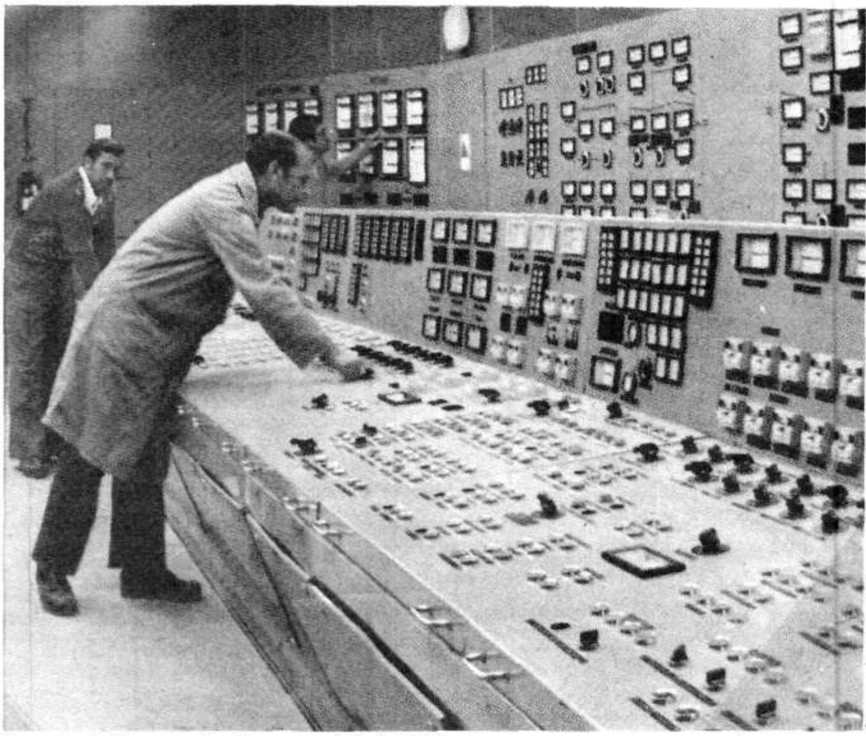
Responding to the planned assasault, the nuclear industry reversed its hands-off stance on the issue and began to mobilise the French Communist Party's affiliated labour union, CGT, for nuclear power. The industry took out advertisements in the labour union's national paper explaining why nuclear development was essential. The leadership of the CGT, mostly skilled workers whose economic well being is tied to an aggressive energy development programme, got the message, and refused to support the assault plan. The Creys-Malville showdown flopped unceremoniously.

The environmentalist effort in France is steered by groups running the anti-nuclear movement in the West, specifically the Natural Resources Defence Council (created by the Ford Foundation) and the British-run Friends on the Earth. Other input has come from European Malthusian fronts such as ECORQPA, based in Geneva. ■

Egypt Goes Nuclear!

After years of planning Egypt seems at last ready to move ahead with its nuclear power development. In November tenders for Egypt's first two nuclear power plants were opened. The tenders are in the process of being assessed and evaluated and if everything goes according to schedule, by the end of May the supplier of the first two plants will be named.

International bids were requested in April 1983 for two 1000 MWe units to be built at a site at El-Dabaa on the Mediterranean coast west of Alexandria. Originally, the final date for submission of tenders for the two units was September 26. But at the request of the bidders, who have found it difficult to mobilise financing for the $3.0 billion project which includes a seaport, roads and other civil construction, the date was pushed back to November 26.



Power station control room at Kafr El-Dawar.

Ambitious programme

Egypt's nuclear power development programme is the cutting edge of an ambitious energy programme (see Table 1). In 1982 Egypt's total energy generation reached 23.35 TWh. Peak load of the unified power system was 3.9 GW, and per capita energy consumption 500 KWh. The new programme, as unfolded by Minister of Electricity and Energy Mohammad Maher Abaza at the IAEA general conference in Vienna in 1982, calls for increasing energy generation more than fourfold, to 101 TWh, and boosting the peak load to 18.2 GW. The per capita annual consumption is to rise to 1485 KWh. Nuclear power will contribute 8.0 GW of installed capacity to the unified system, making it the largest energy generating source in Egypt, by the year 2000.

Egypt has set up an ad-hoc committee under the chairmanship of the Nuclear Power Plants Authority (NPPA) to formulate plans for training Egyptian personnel for operating the proposed nuclear stations. The NPPA will be responsible for the following:

(a) establishment of the organisational structure for the execution of the strategy;
(b) development requirements in the relevant fields of nuclear technology such as safety, quality assurance and quality control, project management, skilled technicians and labour for construction, operation and maintenance of nuclear power plants;
(c) development of adequate infrastructure for domestic participation;
(d) conclusion of necessary bilateral and international agreements to secure reliable sources of supply for nuclear equipment and fuel;
(e) securing adequate financing to cover the required intensive capital investments; and,
(f) assurance of safety and public acceptance of nuclear power.

According to the Ministry of Electricity and Energy, the pattern of energy in the eighties will be characterised by the utilisation of natural gas and local and imported coal, together with the operation in 1990 of the first nuclear power station of 2000 MW at El-Dabba, in addition to full-scale renewable energy (solar, wind, biomass-garbage, solar ponds, etc.) applications.

The programme of the nineties envisages the construction of 6000 MW of nuclear power plants, together with pumped storage and mini-hydro, solar, and other power plants. An extensive programme of desalination of salty and brackish water as well as the electrification of transport and industrial system is included.

Lack of funds

Over the years Egypt's nuclear power programme had been bogged down because of a lack of funds. With the sharp drop in oil prices worldwide, Egypt's financial situation has turned for the worse. As late as 1981 Egypt had been talking in terms of financing some 20 per cent of the $3.0 billion cost for building the two units at El-Dabaa; but now it has become clear that Egypt will be seeking all of the financing from abroad.

Bid specifications and tender

specifications were requested by four groups led by Framatome (France), Westinghouse and C.E. (U.S.A.) and KWU (West Germany). According to Egyptian authorities, the contractor firm will be responsible for complete construction of the plant, installation of all machinery, commissioning of the plant and even the housing for the construction workers. Maher Abaza explained the lack of participation by local industry: "The local industry and construction companies can only participate in the nuclear programme if their standard of quality is raised to the nuclear standard. That is why we realise that the local participation should be phased in slowly and progressively with the progress of the nuclear programme in limited steps. Each step should be carefully evaluated."

The Egyptian authorities appointed the Swiss consultants Motor Columbus under a two-year consultancy contract in 1982 to prepare bid contracts and specifications. Motor Columbus will also be responsible, along with NPPA, for evaluating the tenders. The French company Sofratome had performed the task of site investigation.

The El-Dabaa plant will be licensed by the Egyptian Atomic Energy establishment but the government is already planning to set up a committee to prepare new laws for the licensing and regulation.

With the severe dearth of reactor exports worldwide, reactor exporters from the West are trying hard to get the El-Dabaa contract. However, the reactor manufacturing firms are finding it difficult to mobilise enough funds to bid for a turnkey contract. Recent information indicates that the French, who had earlier planned for a government-to-government sale with full French financing, have been told by the Egyptian government that Egypt would rather not depend on a single source for the complete supply but would welcome an international consortium. The French are reported to be discussing such arrangements with Italian, Belgian, Swiss and South Korean firms, amongst others, while KWU is reported to be discussing collaboration with various West European and Brazilian Companies.

A government initiative

Egypt's decision to move ahead with nuclear power came from the government. The Higher Council for Nuclear Energy was established in 1975 consisting of the President, the Vice-President, the Prime Minister, the Foreign Minister, the Minister of Defence, the Minister of Energy and Electricity and the head of the General Intelligence Agency. In 1981, Egypt ratified the Non-Proliferation Treaty (NPT) and has since established cooperation agreements with France, the United States, the Federal Republic of Germany and Canada.

Egypt also signed an agreement with Australia for the transfer of nuclear materials in February, and in April, an agreement was reached with the Belgian government which would enable Belgian industry to participate in the Egyptian nuclear programme. Memoranda of understanding have also been signed with the United Kingdom and Sweden on safety and training matters, but not on the sale of nuclear power plants. In 1974 Egypt also signed an agreement for the supply of enrichment services for four nuclear plants with the United States Department of Energy.

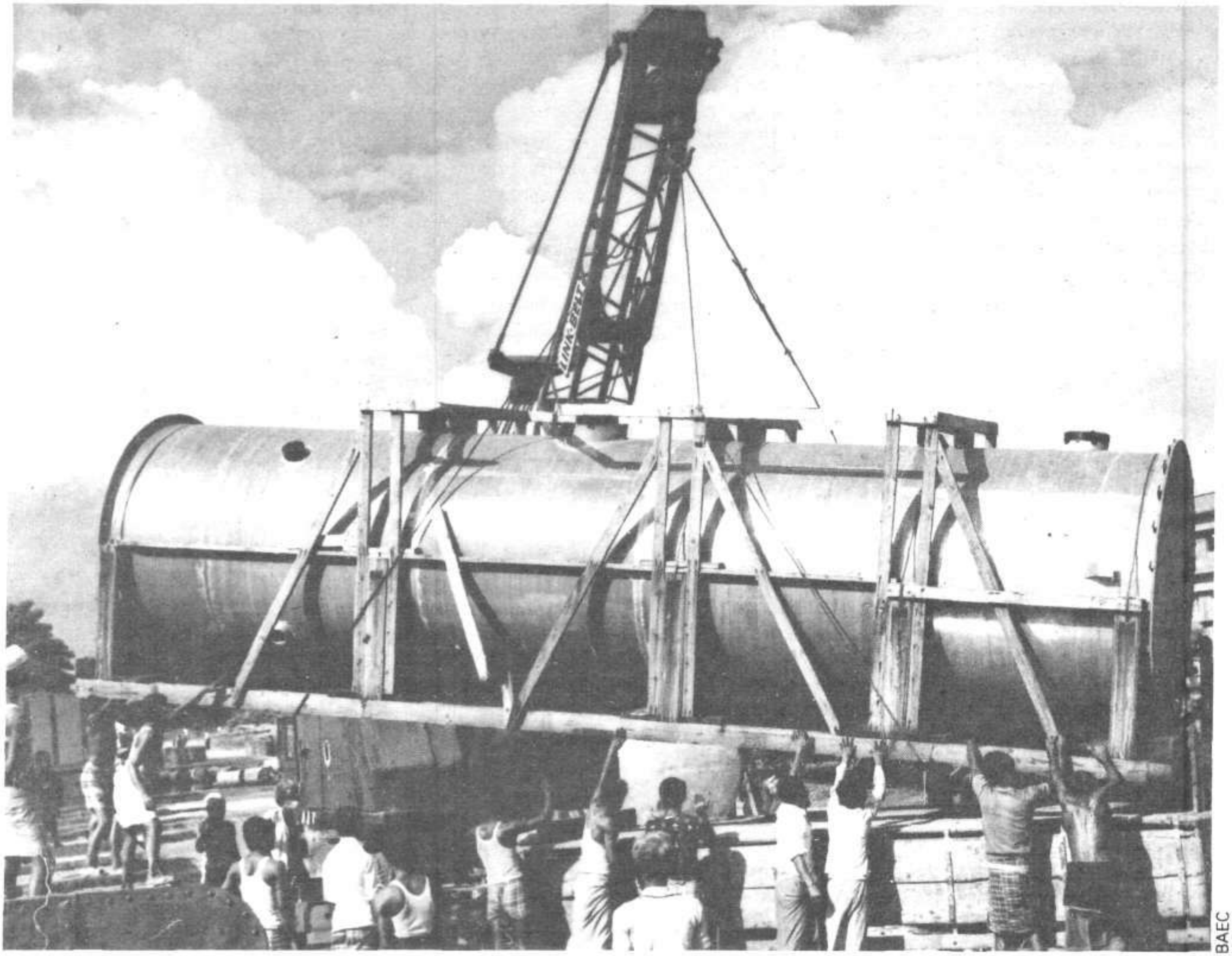
In planning for nuclear power development Egyptian authorities have laid special emphasis in the cost advantage that nuclear power provides. A recent study by the Ministry of Energy and Electricity has shown that for base-load operation a nuclear power station could provide an eleven percent cost advantage over coal, and that with peak demand expected to continue to rise by about 14 percent a year the first two nuclear units at El-Dabaa would be needed by 1991/92.

Table 1

EGYPT'S ELECTRICAL ENERGY GENERATION PROGRAMME

		1952	1962	1972	1982	1990/1991	2000/2001
Population of Eqypt	(Millions)	21.4	27.3	34.9	44	54	68
Electricity Energy Generation	(TWh)	0.423	3.163	7.384	23.350	52.0	101.0
Peak Load	(MW)	125	548	1176	3900	9260	18220
Installed Capacity							
Hydro-electric Power	(MW)	—	345	2445	2445	3267	5950
Oil/gas Steam	(MW)	154	593	1302	1815	5800	4968
Coal Steam	(MW)					1800	4800
Oil/gas Gas Turbine	(MW)			28	462	1360	757
Nuclear	(MW)					2000	8000
Total	(MW)	154	938	3775	4722	12427	24475

Courtesy: WEC 1983



Unloading the core component of Bangladesh's first research reactor.

Bangladesh Installs First Research Reactor

In early November Bangladesh Atomic Energy Commission (BAEC) officials enthusiastically received the first major consignment of components for the research reactor being built by BAEC at the installation site at Savar, about 25 miles outside of Dhaka. A 3 MW Triga Mark-III, the research reactor is this nation's first and will constitute one of the central facilities of the BAEC's Atomic Energy Research Establishment.

While the reactor and its accessories are being supplied by the American firm, G.A. Technologies, Inc., BAEC officials point to the relatively high local content in the overall project in the form of civil, electrical, air-conditioning and ventilation and shielding works. A substantial part of the erection and installation are being carried out by local expertise. Moreover, BAEC is using heavy sand from its project at Cox's Bazar for shield construction, resulting in significant import substitution and further enhancement of local participation in the project.

BAEC's own level of development of in-house capability is demonstrated in the agency's handling of overall project management, coordination of supplies and services, safety analysis review, etc.

The reactor is expected to be critical by August, 1984. BAEC is now finalising programmes for the utilisation of the research reactor. Various research and development works on the peaceful utilisation of atomic energy, including production of isotopes and training of manpower for future nuclear power plant development, is envisaged.

In a future issue, **Fusion Asia** *will report on Bangladesh's power reactor programme as well as implementation and utilisation of the research reactor.*

With 20 Years of Reactor Training

Thailand Still Awaits a Nuclear Power Plan

In 1962 when the Thai Research Reactor (TRR-1) went critical, Thailand became the first Southeast Asian nation to initiate the process of nuclear power development. In 1977 the TRIGA Mark III light water cooled reactor, installed in the original TRR-1 pool, went critical. Yet, inspite of 21 years of research and operational experience in the field of nuclear technology, the Thai government has not yet developed a comprehensive plan for utilising nuclear power to generate electricity.

The seed for nuclear technology development in Thailand can be traced back to the early fifties. Then-U.S. President Dwight Eisenhower, in a speech to the United Nations General Assembly in 1953, proposed an "Atoms for Peace" programme in which both the superpowers would participate. Less than a year later, in 1954, the Thai Atomic Energy Commission for Peace established a national committee to deliberate on atomic energy development and advise the government accordingly. In the same year a U.S. "Atoms for Peace" mission visited Thailand to discuss future cooperation between the two nations.

TRR-1

The first "Agreement for Cooperation Between the Government of the United States of America and the Government of the Kingdom of Thailand Concerning Civil Use of Atomic Energy" was signed at Bangkok on March 13, 1956. When the International Atomic Energy Agency (IAEA) was established in Vienna in 1957 to devote its activities exclusively to the peaceful uses of atomic energy as proposed by President Eisenhower, Thailand became a member.

Once Thailand joined the IAEA, the development of atomic energy took on momentum in the country. In 1958 the Thai AEC awarded a contract to a U.S. company to design and install a 1 MW swimming pool-type research reactor. In January 1961 groundbreaking and site development for the research reactor, which later came to be known as TRR-1, began in earnest. At that time the project was handled as a "national project" by an ad hoc committee under the supervision of the Thai AEC.

Two years later the construction phase of the reactor project was completed. In 1962 TRR-1, located at the Bangkhen campus of Kasetsart University in Bangkok, went critical. Although the reactor was designed and installed by an American company, Thai participation in project management, construction and installation, testing and commissioning of the reactor and ancillary systems was as high as 90 percent.

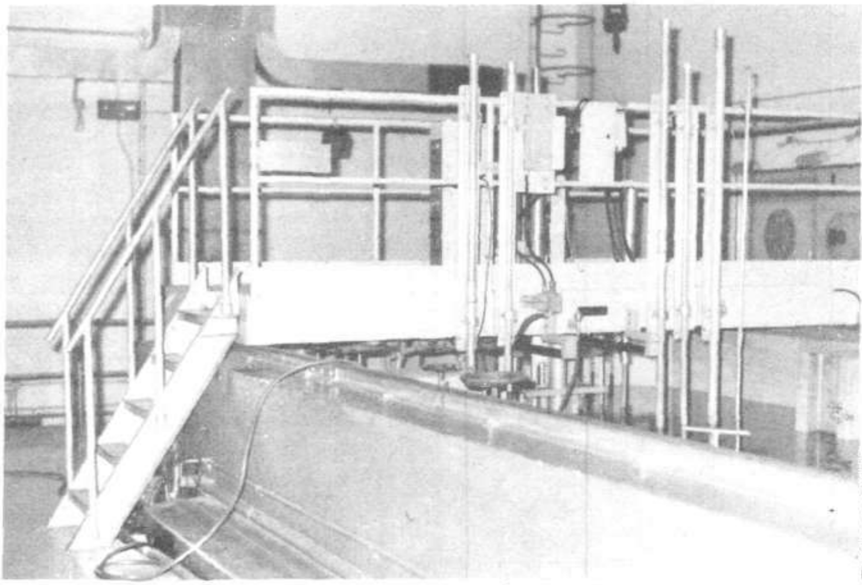
OAEP Established

In 1961, a few months before the TRR-1 commissioning, the Thai government established the Office of Atomic Energy for Peace (OAEP) as the functioning arm of the AEC under the Office of the Prime Minister. OAEP was subsequently transferred to the Ministry of National Development, then to the Ministry of Industry, and finally in 1979 to the Ministry of Science, Technology and Energy where it is now located. OAEP's responsibilities include regulatory enforcement pursuant to the Atomic Energy for Peace Act; coordinating functions with regard to nuclear affairs including foreign relations; support of research and development in nuclear technology; and operation of a national research reactor centre. Although one of its main objectives is development of Thailand's Nuclear Energy Master Plan, the OAEP has received little encouragement in this. At the present time there is no distinct plan to go for nuclear power development for electricity generation, although some officials in the OAEP believe that Thailand's first nuclear power plant may get built by 1995.

No Nuclear Power Plan

The Thai government's smugness on the development of nuclear power is perhaps understandable from the point of view that Thailand now has surplus energy generating capacity and is in fact in a position to sell its surplus power to the government of Laos across the border. But this energy surplus has been attained by meeting total energy demand with

Thailand's Office of Atomic Energy for Peace in Bangkok.



The Thai research reactor, TRR-2, is a swimming pool type.

purchases of high-priced imported fuel oil. More than 75 percent of the generation cost is the cost of fuel oil. In order to deal with the resulting high price of electricity that now exists, the Thai government is wrongly pushing energy conservation schemes. The price of electricity has been increased substantially during 1982 to cut down on consumption.

Enforcing energy conservation in a country which has a very low energy generation capacity overall can be disastrous for Thailand's future industrial development plans. While Thailand's economy is growing at an annual rate of almost 10 percent, energy growth during the last two fiscal years was a meagre 3.5 percent. What that means is that Thailand, instead of becoming an industrial nation in the near future, will have to continue to rely more heavily on a manual labour-based raw commodity supply. By rejecting advanced technology which can be the motor for its industrial development, the Thai government has adopted a policy which is inefficient and cost ineffective.

Today Thailand's installed power capacity is close to 4000 MW. By 1988, according to the Electricity Generation Authority of Thailand (EGAT), this figure will rise to 7700 MW. In 1982 the per capita installed power capacity is 0.8 KW. While the Thai government is showing a lot of concern about the environment and ecology in general, it is making extensive plans to burn natural gas to meet future energy needs instead of developing the least-polluting energy source, nuclear power.

Developed Radiation Technology

Although Thailand's nuclear power development policy is less than adequate, the Thai OAEP has done significant work in the use of its research reactor for radioisotope production and radiation technology work. **Fusion Asia** discussed this programme during a recent visit to Bangkok with OAEP Deputy Secretary General Ratana Pumlek. Dr. C. Banditsingh of OAEP's Biological Sciences Division joined the discussion to elaborate on the progress being made in the use of isotopes in agriculture, food preservation, and other areas.

OAEP's Cobalt-60 Irradiation Facility, which was completed at the end of 1971, is used to irradiate seafood and packaged products. The irradiation power of this facility was increased to 48,980 Curies in 1981 and this extended the research work by utilising gamma rays in other areas. Gamma ray radiation is used to enhance the shelf-life of meat, poultry and seafood, to slow down the ripening process of perishable fruits, and to stop the germinating process in spuds such as onions and potatoes.

Substantial work has been done through activation analysis of soil. The method, which was adopted about a decade ago, is widely used to help pick the type of crop rotation that would be suitable for different kinds of soils. Radioactive tracking techniques have also helped in studying plant absorption of minerals and fertilizers. Irradiation of seeds in mutation techniques or seed selection helped Thailand to develop a new glutinous rice variety five years ago. This variety of rice gives a much higher yield than the traditional seeds and is much more disease resistant. Radiation techniques are also being used for insect control.

In the past six years more than 50,000 patients per year have been either diagnosed or have received treatment by irradiation. The number of patients treated was limited by lack of equipment and qualified doctors. In the irradiation facility, Iodine-131 is widely used for diagnostic purposes as well as for thyroid treatment. Iodine-131 is also used in analysing kidney disorders and problems in the blood circulatory system.

The OAEP also provides industrial radiography to various industries such as oil refineries, cement plants, and paper mills on a regular basis. OAEP provides neutron activation and x-ray fluorescence in mineral research work. Gauging equipment using a radiation source is also widely used in the quality control sections of large industries. The most modern such system is now used in the Siam Kraft Paper Mill. OAEP is also involved in a joint project with the Japan Atomic Industrial Forum and IAEA on the use of nucleonic control systems in paper manufacture.

Manpower Development

OAEP has a total staff of about 300 scientists, engineers and technicians in eleven divisions, organised into three broad groups according to major task areas. The research staff is concentrated in the Radiation Measurement Division, Waste Disposal, Isotope Production and other divisions connected with direct applications and environmental issues. The small Physics Division has a staff of 10, including four PhDs. To take best advantage of the limited resources of well-trained manpower, OAEP personnel function for the most part in project teams that overlap divisional boundaries. Current special projects being worked on are the pilot-scale production of yellow cake, nuclear-grade uranium and thorium oxides from local ores; improvement of isotope production capabilities with special emphasis on Technitium-99m; and nuclear site selections studies (undertaken in conjunction with CESEN of Italy).

The research reactor is run by 14 operators and supervisors, generally nuclear engineers who have undergone IAEA and other training as well as a one-year programme at OAEP covering both theory and operation of the reactor. As Deputy Secretary General Ratana Pumlek emphasised to **Fusion Asia**, the operators must know every aspect of the reactor's functioning and make-up in detail. OAEP in turn offers training to personnel outside OAEP in such areas as radiation safety, nuclear instruments maintenance, industrial radiography, and the application of nuclear-based techniques—carbon dating and so on—in fine arts and archeology.

South Korea : A Second Nuclear Plant in Record Time

Working round the clock the Korean Electric Power Corporation (KEPCO), in conjunction with Atomic Energy at Canada Ltd., completed the Wolsung Unit 1 Heavy Water Power Reactor in less than six years. The 628 MWe CANDU type Heavy Water Reactor went into operation last March, the second nuclear power reactor in South Korea to go critical.

South Korea's success in completing the power plant in record time is testimony to the effectiveness of the country's manpower development programmes—in areas of nuclear plant operation in addition to well known capabilities in construction and engineering. It also testifies to the foresight of Korean leaders in launching a nuclear research and development programme more than twenty years before their first power reactor was commissioned.

South Korea's nuclear power development programme, perhaps the most ambitious among the developing nations in Asia, was formed in the early fifties. Korea joined the International Atomic Energy Agency (IAEA) on August 8, 1957. The first "Preliminary Feasibility Study of Nuclear Power Generation" was undertaken by the Office of Atomic Energy—the government agency responsible for all peaceful uses of atomic energy, since renamed the Korean Atomic Energy Commission—following its establishment in 1959.

ROK

The Kori I nuclear power plant in South Korea.

In 1975 South Korea ratified the Treaty on the Non-Proliferation of Nuclear Weapons, and in the same year reached an agreement with the International Atomic Energy Agency for the application of safeguards in connection with the Non-Proliferation Treaty. Since then, South Korea has signed agreements with the United States, Japan, France, Canada, Spain and Australia concerning cooperation in peaceful uses of nuclear energy and the transfer of nuclear material.

Choosing Nuclear

South Korea's nuclear power development policy was motivated by two basic tenets: first, the uncertainty concerning Arab oil supplies and lack of energy generation sources in Korea itself. In Korea, as in many developing nations which do not possess an abundant supply of oil and coal, nuclear power became the obvious choice for commercial energy needs. It became even more relevant to South Korea as the planners realised that nuclear power is the most versatile and reliable energy source capable of meeting the soaring energy demand associated with Korea's economic development plans.

The second consideration in Korea's bid for nuclear power development was the nation's increasing energy consumption as a result of the rapid pace of industrialisation that has been taking place over the last decades. Figures supplied by the South Korean government indicate that various forms of energy consumed in 1981 totalled the equivalent of 45.9 million metric tons of oil, compared to 20.9 million metric tons in 1971—more than a doubling of energy consumption in ten years. Over 75 percent of the energy consumed in 1981 was imported, mostly in the form of crude oil and some in coal and nuclear fuel.

To lessen such a high dependence on oil imports, Korea decided to move quickly in developing new alternative sources of energy—principally nuclear—to facilitate future industrial growth. A long-term programme is now being implemented to rapidly boost the share of nuclear power—which is considerably cheaper than generating electricity by burning oil—in the total electricity generated. The country has in fact stopped building any more oil-fired power stations.

The overall power generating capacity in South Korea stands at 9.8 gigawatts. By 1986, conservative estimates suggest, the installed power generating capacity will rise to 17.6 gigawatts and by 1991 this figure is expected to be as high as 27 gigawatts—an almost threefold rise in ten years. By 1991, according to present plans, nuclear power will be contributing 41 percent of South Korea's total electricity generation.

Nuclear Planning

The first nuclear reactor, Kori I, a 587 MWe Pressurized Water Reactor, was commissioned in 1978. The second unit of the cluster at Kori, a 650 MWe PWR, is scheduled to be commissioned in 1984. The nuclear programme indicates that by 1986 at least nine nuclear reactors, with a total generating capacity of 6.5 gigawatts, will have been commissioned by the KEPCO. By 1986 the contribution of nuclear power to South Korea's power grid is expected to be 31 percent.

Well before Kori I was commissioned in 1978 the OAE had constructed a 100 kilowatt Triga Mark II Research Reactor which went critical in 1962. Only four years after the research reactor went critical, the South Koreans set up a Radiological Research Institute (RRI) and Radiation Research Institute for Agriculture (RRIA). Basic research was carried out in radioisotope techniques, in radiosterilisation of medical products, radiation curing of plywood, and textile improvement by radiation graft. Special emphasis was also placed on the application of radioisotopes in the production and development of radiation sources and radioisotopes and radiation mutation research.

The Triga Mark II Research Reactor also became the neutron source for neutron physics research. Simultaneously work in radiochemistry on the use of radioactive tracers for radiochemical research and flux and thermal neutron use for radiochemical analysis were carried out. South Korea also used the research reactor in developing its nuclear medicinal research with special emphasis on RNA metabolism, anticancer action mechanisms and an epidemiological study of cancer.

High Efficiency

South Korea's success at Wolsung in completing the plant in six years can be attributed to the highly industrious and skilled Korean staff. Although the design and construction of Wolsung Unit 1 were primarily controlled by the AECL, the highly skilled South Korean construction capability played a major role in the plant's speedy completion. In commissioning the Heavy Water Reactor, KEPCO workers played a major role. In 1978 KEPCO had selected 43 persons, many who had gone through CANDU reactor training programmes. The Canadian commissioning staff arrived at the plant site in 1982 to establish work protection procedures to ensure the safety of the personnel and equipment and to agree with the construction and engineering divisions on the criteria for the turn-over of systems and equipment to the commissioning division.

Another factor which led to timely completion of the project was the co-ordination of design, procurement, construction and commissioning groups into a fully integrated planning schedule. Task forces were established to avoid disruption of completed or ongoing site work caused by late design changes. Only those changes which were deemed essential to plant safety or operation or which were required for licensing by the regulatory committee, were allowed to be made.

Since the Wolsung Unit 1 was the fourth 600 MWe CANDU reactor built, the AECL had the benefit of experience gained over the years to apply to the Wolsung project. ■

Table 1:
STANDARD PLANNING AND COMMISSIONING DURATIONS COMPARED WITH WOLSUNG TARGETS AND ACTUAL DATES.

PERIOD	STANDARD	WOLSUNG 1	ACTUAL
Phase A	24 months	18 months	18 months
Phase B	1 month	2 weeks	9 days
Phase C	3 months	1 month	4 months
Phase D	9 months	1 month	1 month
Total	37 months	21 months	23 months

Phase definitions

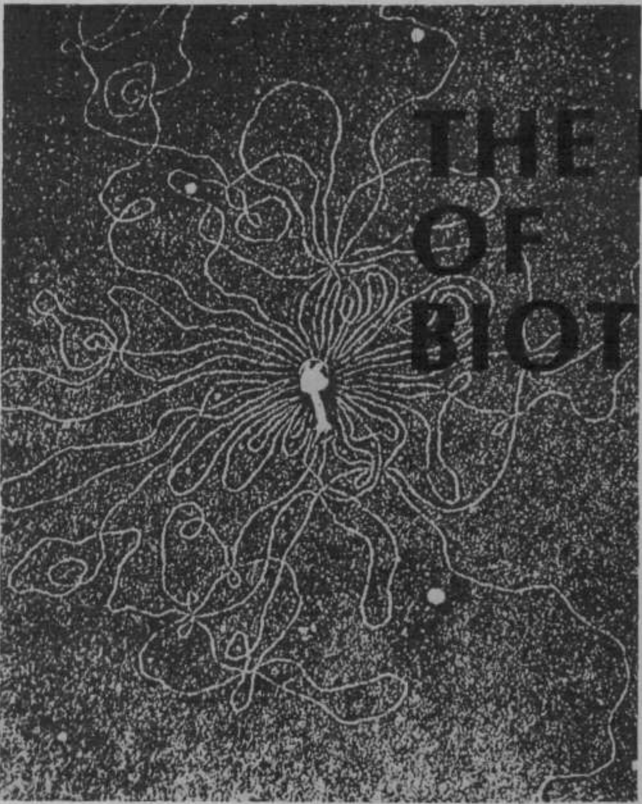
Phase A: Turnover of switchyard and high voltage electrical systems to completion of placing all plant systems and equipment into service (except turbine generator)

Phase B: Low Power physics tests

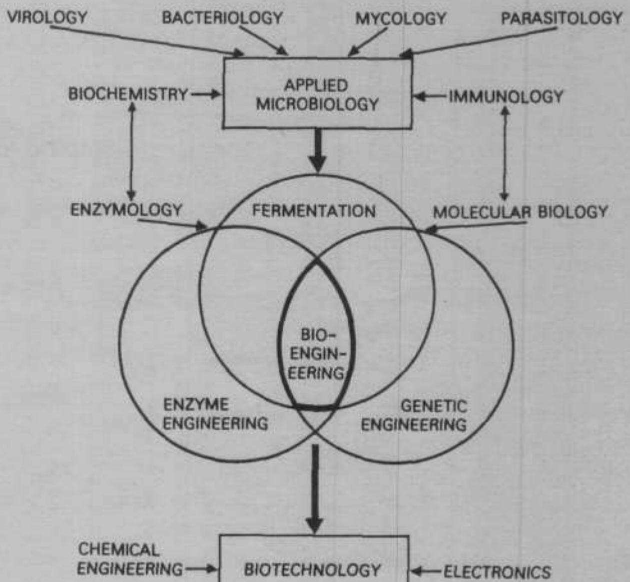
Phase C: Integrated plant start-up to full power

Phase D: Completion of tests at full power and demonstration of capability for commercial operation.

THE PROMISE OF BIOTECHNOLOGY


A.K. KLEINSCHMIDT

DNA of the T2 bacteriopnage



Biotechnology is a term that has been coined only recently to encompass the wide range of existing and imagined technologies based on biological, as opposed to mechanical, processes. While in this sense the thousand-year-old practice of making alcohol is as much a part of "biotechnology" as modern-day gene cloning, it is the latter which properly characterises the field. Biotechnology is defined by the ability to intervene into biological processes to qualitatively speed them up or otherwise transform them to conform to Man's needs. It draws on a wide range of disciplines and has already demonstrated great potential for major applications in medicine, industry and agriculture. Together with ongoing work in high energy physics, it is forthcoming breakthroughs in the context of biotechnology that will transform human knowledge and existence in the next century.

The emergence of biotechnology in the past several years is based on two major discoveries: first, the discovery that genetic material of one species could be isolated, cut out, reintegrated and transferred into a second species and then function in a normal way, i.e., the technique of *recombinant DNA*; and, second, discovery of the technique of *cell fusion*. Suddenly genetic manipulation across both the "time barrier"—traditional methods of breeding and selection took years to fashion a new variety or organism—and the "species barrier" was possible. Entirely new organisms could be created to specification, virtually overnight.

The most immediate applications have been in the medical field—in terms of both diagnostics and therapy, and including the production of drugs and pharmaceuticals. Monoclonal antibodies are one major new tool made possible by the ability to carry out somatic cell fusion.

Recombinant DNA technology has opened the way for mass production in pure form of a variety of therapeutic proteins such as insulin, growth hormones, interferon and vaccines—which have hitherto been either non-existent or inefficiently produced.

Even more fundamental, the new techniques make it possible to mount a new effort to fathom the processes involved in such qualitative biological change as accompany aging and cancer. Together with the development of x-ray laser probe capability in the near future, these techniques will permit "nondestructive testing" with living tissue, giving further enormous impetus to this critical research.

The breakthroughs in genetic engineering have given a boost to industrial microbiology, where protein engineering and the development of newer and better catalysts promise more efficient production of chemicals and pharmaceuticals, the development of entirely new products via bioconversion, and the possible transformation of the chemical industry.

The use of microorganisms in waste treatment, pollution control and in metallurgical processes have new vistas opened by the ability to engineer new, more efficient and hardier microbes to carry out specific operations—from degrading highly specific toxic chemical compounds to the extraction of particular metals from low-grade ores.

Because biotechnology was boosted into public favour in the late 1970s as the answer to the energy crisis, many view the developments in industrial microbiology—where indeed the most intense activity is now centered—as heralding a new industrial revolution based on a shift from energy-intensive processes to "natural," energy-conserving biological processes. Industrial microbiologists will certainly continue to "fine tune" microbial processes, and develop new ones with important, useful and surprising applications. But as far as an industrial revolution is concerned, these developments are likely to be swept aside by the truly revolutionary impact that emerging laser and plasma technologies—with their much higher energy densities—will have in effecting a total transformation of industrial processes as we know them.

Beyond the Green Revolution

In fact, it is in agriculture that biotechnology's potentially most significant impact lies. Yet, while the application of the new genetic engineering techniques in agriculture is theoretically possible, it is not an immediate practical prospect at this time. The genetic feats that produced the high-yielding varieties of grains and the "green revolution" they made possible were based on standard, if deliberately and intensively pursued techniques of breeding and selection. Inspite of the invaluable practical result of these achievements, they were not accompanied, by a comparable advance in knowledge of the molecular genetics of plant growth.

At issue is the fact that plants are relatively higher organisms. The genetic determination of those aspects of plant growth that are the obvious targets for improvement—e.g., disease resistance, stress tolerance, nitrogen fixing capability, and photosynthetic capacity—is not well understood. In each of these cases, complex systems are involved which depend on many genes of unknown identity interacting in ways whose physiology, biochemistry and regulation remain largely unknown. Assumptions of straightforward expression of a discrete function by a single gene, such as enhanced protein content, have been repeatedly belied in experimentation with plants. Efforts to genetically engineer one aspect of plant growth, say nitrogen fixation, repeatedly run into problems which beg the question of the overall metabolism of plant growth. Work now proceeding in the application of recombinant DNA technology to yeast, like plants a eukaryote but of lower order, may help to bridge the gap from the now virtually routine recombinant DNA work with bacteria and other prokaryotes to its application in the eukaryotes and higher organisms such as plants.

Tissue culture and protoplast fusion have great potential. The individual plant cell can be isolated, bred and selected for specific traits and fine-tuned to respond to specific environments. New plant varieties could conceivably be developed in this way.

In the meantime, agriculture will be richly benefitted by the application of genetic engineering techniques to the improvement of microorganisms beneficial to plant growth, such as the *Rhizobium* bacteria that fix nitrogen in symbiotic relationship with legume plants.

Policy Issues

Since by contrast with space research or even atomic energy in its earlier phase, biotechnology is largely in the hands of the private sector in the developed nations where it is most advanced, certain specific problems are posed, in particular for developing nations. One problem is the scewing of research efforts toward the most readily marketable areas. In the United States, for instance, this is most strikingly demonstrated in the fact that federal investment in medical research is fully twenty times greater than that in agriculture—inspite of the obvious urgency and enormous potential of the latter.

For developing nations a broader problem is that of scientific collaboration and technology transfer. Here it is widely acknowledged that vigorous national programs to build up capabilities in the component fields of biotechnology must be supplemented by a serious international undertaking where the most advanced work can be facilitated in an ongoing and centralised manner such that both the results and the techniques are available free of charge to participating nations.

The most serious challenge developing nations face is that of designing national biotechnology programmes and strategies which are optimal from the standpoint of both practical results and enhancement of the nation's overall scientific and economic capability. The temptation will be to capitalise on industrial microbiological applications to the possible detriment of longer-range requirements for fundamental biological research and basic research work in agriculture. The overall biotechnology programme must at the same time be conceived properly within the framework of the country's industrial-economic development, making sure that the apparent immediate gains of the various biotechnologies are realistically evaluated over the longer term and in light of the full range of advanced technologies. Under no circumstance should the notion be entertained that biotechnology represents an alternative, even temporarily, for basic infrastructural and heavy industrial development. Similarly, there should

Internat'l Centre Proposed

In 1981 a meeting of scientists convened by UNIDO concluded that establishment of an international centre for research and training in biotechnology geared toward the requirements of developing nations in building up their own national programmes was essential. The group, including several scientists from developing nations currently working in biotechnology research in advanced countries, visited fifteen capitols to discuss the proposal.

The expert's report summarised the thinking of those consulted and spelled out what the centre might look like. It is conceived as an independent institution financed by contributions from both developed and developing countries, whose operating budget would be equivalent to what a large chemical company might invest in a single American university for research. The centre would be staffed by about 50 scientists, 26 postdoctoral fellows and 100 visiting trainees.

The staff, it is proposed, should consist of teams of molecular geneticists, biochemists, microbiologists, protein and nucleic acid chemists, bioengineers, computer specialists and others organised in five interacting units.

It was further recommended that priority in the R&D plan be given to: tertiary oil recovery from petroleum wells; energy and fertilizer from biomass; improvement of fermentation techniques; development of improved human and animal vaccines; improved agricultural products using phytochrome genes; and drugs and pharmaceuticals for tropical diseases.

Choosing a location for the centre has proved difficult. At a December 1982 meeting in Yugoslavia representatives of 35 nations set up a second team of experts to visit and evaluate each of the six proposed locations—Belgium, Cuba, India, Italy, Pakistan and Thailand. In its 60-page report presented in May 1983, the team concluded that only Belgium, Italy and Thailand could provide the "range and combination of qualities" to support a centre of "high excellence," a conclusion that did not find unanimous acceptance. At a third meeting in Madrid in September 1983, representatives of 44 nations still could not come to an agreement. As it stands at this writing UNIDO is to have reviewed the deliberations and consulted all concerned by 31 January 1984 anda ministerial meeting in April will take a final decision.

Meanwhile the OECD countries, with France and Great Britain in the lead, have moved to set up an International Technology Network. By contrast with the UNIDO proposal, the ITN will not involve itself in areas of applied research, where these nations are anxious to protect lucrative trade secrets. The brainchild of a working group established by the 1982 economic summit of OECD nations at Versailles, the ITN was officially inaugurated in September by French Industry and Research Minister Laurent Fabius.

be no illusion that the biotechnicians can deliver the amount and density of energy required for these basic and essential tasks.

The Challenge to Prevailing Theory

Ultimately the most far-reaching effect of the unfolding biotechnology revolution will be to transform our understanding of the origin and nature of living processes. An analogy to space research is to the point. There Man's ability to perfect the technology of satellite reconnaissance to probe the farthest reaches of our solar system and beyond has produced findings—like the content of Saturns rings, for instance—which challenge the foundations of current physical theories concerning the Universe and its origins. Similarly, even while the new biotechnological techniques are proving reliable tools to make important advances in medicine, agriculture and industry, experimental results from the explosion of research projects will invariably raise a direct challenge to current evolutionary theory and to many of the most basic tenets of biology grounded in the work of Mendel and Darwin.

Already the foundations have been shaken, for example, by the discovery that the DNA making up a gene is not a simple structure but one which consists of both coding and non-coding areas. Unanticipated problems with gene expression following successful transfers have prompted a re-examination of certain tenets of current theory. Together with the demonstration some years ago that certain nongenetic transformations are hereditable, anomalies such as these beg the question of a global determination of genetic events, where the discrete genes are redefined to assume new qualities under a globally-interacting array of molecular constituents that a turn reflect the larger interacting ecology in a negentropic Universe.

The following pages provide a glimpse into the work of biotechnology. Our aim is neither a comprehensive, nor necessarily authoritative presentation of this broad field. Rather we want to introduce some aspects of the revolution whose progress will be a continuing focus of attention in *Fusion Asia.* Two pieces, one on photosynthesis and another on the unique characteristics of a special family of enzymes, review work in two specific areas. Both proceed from the standpoint of the evolution of living processes, presenting their material in terms of the insights provided in that larger framework.

We also wanted to look at biotechnology through the eyes of those who are engaged in it. Dr. Subba Rao of the Indian Agricultural Research Institute and Dr. Pornchai Matangkasombut of Mahidol University in Bangkok were kind enough to discuss their work, in agriculture and medicine respectively, and their view of the field as a whole with *Fusion Asia,* and those interviews are included. Dr. Ananda Chakrabarty of the University of Illinois granted us permission to print excerpts of a report on his work delivered to a Paris audience recently.

—The Editor

Photosynthesis was the first great technological revolution, comparable in its effects only to the potential of man-made fusion energy to transform the planet today.

Photosynthesis From an Evolutionary Standpoint

by Delia Araujo de Lozano

THE FIRST ENERGY CRISIS that confronted life on Earth occurred some 2 billion years ago, when the earliest living organisms, fermentative ones, had nearly exhausted their organic energy sources. Life overcame that crisis by evolving a revolutionary new technology—photosynthesis—which, by allowing the capture of the Sun's energy, totally redefined the then existing resource base and produced an exponential increase in the energy throughput of the biosphere.

In that respect, photosynthesis is the model for the frontier technologies that must be developed to solve today's so-called energy and resource crisis, such as the fusion torch, which has the potential to economically transform low-grade ores and even garbage into usable resources, and fusion power itself, which will produce a limitless supply of low-entropy energy from the deuterium in ordinary sea water.

What was the evolutionary crisis that preceded the appearance of photosynthesis?

In the beginning of life, there was no free oxygen in the atmosphere; oxygen existed only in water vapor and other compounds. The early organisms produced energy without oxygen by the process of fermentation, breaking down organic nutrients such as sugar by means of oxidation-reduction reactions into energy, CO_2, and various acids. However, fermentation was a very inefficient process.

First, the fermentation organisms depended on a nonrenewable energy resource—the organic nutrients. These organic substances were formed by inorganic means, such as electrical storms and magnetic discharges, over a long period of time. It took approximately 2 or 3 billion years to form the sugars, proteins, and other substances used as nutrients by the fermentative organisms.

The primitive organisms consumed these organic nutrients much faster than they were formed by inorganic means; and the expansion on the number of fermentative organisms used up the organic nutrients at an increasing rate. Clearly, this technology was not able to support life indefinitely.

The second limitation concerned the technology of fermentation itself. All living organisms, in the same form that society does, need (1) a mechanism for transporting energy within the cell without loss; this is adenosine triphosphate (ATP), the "energy transport molecule," and (2) a mechanism for carrying hydrogen for reducing substances within the metabolism—for example, for transforming nutrients into amino acids; this is reduced nicotinamide adenine dinucleotide phosphate ($NADPH_2$), the "reducing power molecule."

The fermentative organisms produced ATP by breaking down organic nutrients. However, they were not able to produce reducing power, essential for the growth of the cell, by fermentation. To produce the reducing power molecule, the fermentative organisms used a second metabolic pathway, expending additional energy in the process. The fermentative organisms had to work, in effect, twice as hard to grow. Fermentation by itself was not efficient enough to support more complex life on Earth.

The Photosynthetic Revolution

Fermentative organisms produced tremendous amounts of CO_2 and excreted simple substances such as ethanol and acetic acid, thus transforming the primordial atmosphere. The fatal paradox was that as the growing population of fermentative organisms increased the energy throughput of the biosphere, their growing numbers were depleting their own nonrenewable resource base (the organic nutrients). For life to continue to evolve, there had to be a technological jump, and the higher technology was photosynthesis.

In response to the first energy crisis, the metabolisms of existing organisms changed into new technological manifolds. Some organisms continued with the same functions. Others changed into simpler organisms such as bacterial spores. Still others changed into photosynthetic ones.

The early photosynthetic organisms may have been types of the photo-organotrophic bacteria that still exist today.[1] These bacteria are able to capture light through a mechanism known as Photosystem I (PS I); the energy captured by this pigment complex is then transformed into ATP. This more advanced technology could, thus, overcome the first deficiency of fermentation: Organisms equipped with PS I had access to a new, unlimited energy source for ATP production.

As sources of reducing power, these primitive bacteria used ethanol, acetic acid, and other semi-oxidized substances—the waste products of fermentation; which otherwise were toxic for the nonphotosynthetical organisms. But although these early photosynthetic bacteria could change the primitive environment, redefining the fermentation process and increasing the energy throughput of the biosphere by capturing sunlight, the same deficiency remained as had existed with fermentation: namely, the inability to produce reducing power from the same energy source as ATP and the continued dependence of reducing power production on a nonrenewable resource—organic waste.

A second type of bacteria, photolithotrophic bacteria, may also have been an early photosynthetic organism. These bacteria use the same machinery to capture light as the photo-organotrophic bacteria, but they use a different reducing power source: inorganic materials such as hydrogen, H_2, and sulfuric aicd, H_2S—which were present in the primordial atmosphere that existed when the first energy crisis occurred. This group of bacteria suffered from the same kind of deficiency as the other photosynthetic bacteria: They depended on nonrenewable sources of reducing power, which they expended additional energy to produce.[2]

The early photosynthetic organisms had the further limitation that as they multiplied, they could not support the growth of fermentative organisms (on whose waste products they were dependent); their production of carbohydrates from sunlight was sufficient only for their own development.

Photosytem II

When the organic material used by the earliest photosynthetic bacteria as a source of reducing power began to decrease, the utilization of light as an energy source evolved into a more efficient process, maintaining the increased energy flow into the biosphere. Photosytem II (PS II) was the more advanced machinery for light capture. Although the pigment complex of PS II had the same chemical composition as that of PS I, the complex had a higher order structural organization. Photosynthetic cells equipped with this additional machinery could produce reducing power from the same energy source that they used to produce ATP. Thus, the photosynthetic organisms that acquired PS II were able to take the more oxidized excretion product of fermentation—CO_2—and make carbohydrates from this substance, using ATP and reducing power produced from sunlight. These new photosynthetic organisms diminished the time in which the organic substances like carbohydrates were formed from billions of years by inorganic means to hours, in our era, by means of green plant cells.[3]

Photosynthesis with both PS I and PS II—as exists in green sulfur bacteria, blue-green algae, and today in more advanced, green plants— was more efficient than with PS I alone; in fact, PS II redefined PS I as its "collaborator" in producing more energy more efficiently for the cell.

Furthermore, photosynthesis with PS I and PS II extended the life of the more primitive organisms—the fermentative organisms and photosynthetic organisms with only PS I—because it produced carbohydrates (organic nutrients) for these organisms. Photosynthesis with PS I and PS II also produced a tremendous increase in the energy throughput of the biosphere, introducing an at that time unknown and noxious substance—free oxygen.

When the content of the atmosphere changed, a new kind of organism evolved—the respiratory organisms. These organisms used the same energy source as the fermentative organisms, but they used it more efficiently, because they were able to break down carbohydrates more completely to produce ATP and the reducing power molecule. Respiration was the next "technological leap" able to extract more energy per carbohydrate molecule than the previous technologies. Respiration, in turn, produced CO_2, which was used by photosynthetic organisms for forming more carbohydrates with sunlight (Figure 1).

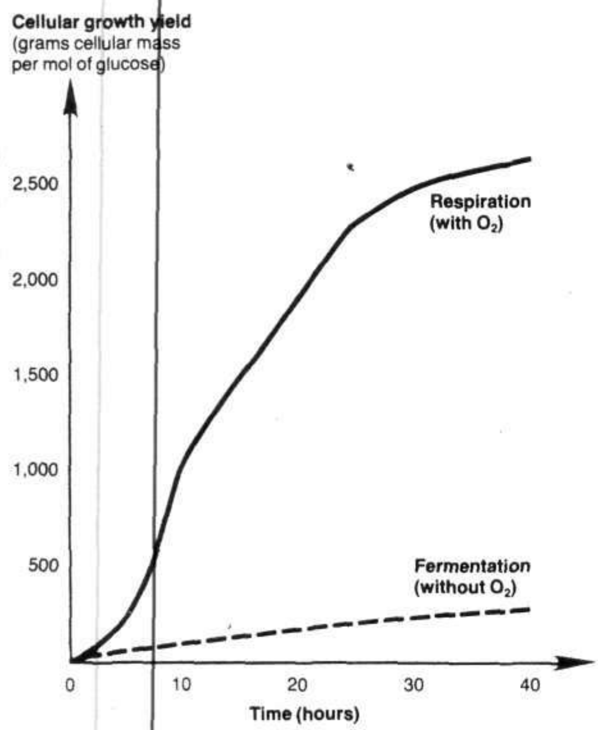


Figure 1
CELLULAR GROWTH WITH RESPIRATION AND FERMENTATION

This graph compares cellular growth (grams of cellular mass per mol of glucose) over time for the same microorganism (S. Faecalis) undergoing respiration and fermentation. Respiration produces much greater cellular growth than fermentation because of the greater energy production (36 molecules of ATP) per glucose molecule.

Today, all the bread in the world and all the meat in the world are produced by photosynthesis, through the production of cereal, grain, and foliage. All of the oxygen present in the atmosphere is produced by photosynthesis. Nonphotosynthetic living organisms are completely dependent for their carbon and energy requirements on organic nutrients formed by photosynthesis. The interaction between photosynthetic and nonphotosynthetic organisms maintains the biospheric concentrations of CO_2, O_2, and H_2O. Photosynthesis is the process that allowed and continues to allow the existence of higher organisms in the biosphere.

How the Technology Works

Photosynthesis in green plant cells consists of two interconnected phases. The first is light capture and the transformation of light energy into chemical energy in the form of ATP (the energy transport molecule) and $NADPH_2$ (the reducing power carrier). The second phase is the capture of CO_2 and its transformation into carbohydrates (such as sugar), using ATP and reducing power.

The machinery in charge of light capture consists of a complex of pigments, of which chlorophyll is the main one. The pigments are grouped geometrically in functional units, with photochemical conversion centers and other catalysts located in membrane-bounded, flattened sacs known as thylakoids. In higher plants, these structures are concentrated in special organelles—the chloroplasts; in bacteria, they are located in the bacterial membrane itself.

There are two main kinds of chlorophyll in plant cells, *a* and *b*, which have the same chemical properties and only a few structural differences. Chlorophyll *a*, the main functional pigment in green higher plants, contributes to light capture, along with a number of "accessory" pigments. Chlorophyll *b* is present in about one-third the concentration of chlorophyll *a* in green plants. In brown algae, we find a third kind of chlorophyll, chlorophyll c. In addition, there are some nonchlorophyllous short-wavelength absorbing accessory pigments such as the carotenoids (alpha and beta carotene) and lutein among others.

Photosystems I and II have somewhat different compositions of pigment complex. Chlorophyll *a* is the main constituent of both, but PS II has a greater concentration of accessory pigments than PS I. The photosystems respond to different frequencies of light: PS I can be excited by sunlight wavelengths of more than 680 nanometers and less than 700 nm, whereas PS II can be excited by wavelengths of less than 680 nm. There are also geometrical differences between the two photosystems: PS II is located inside the thicker part of the chloroplast membrane, whereas PS I is located in the thinner, connective portions of the membranes.[3]

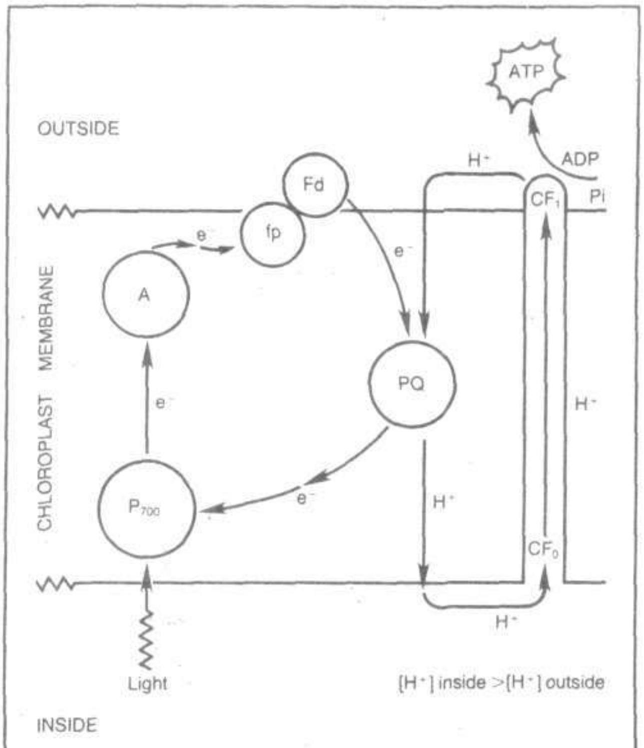


Figure 2
ARNON'S CYCLIC (ANOXYGENIC) PHOTOSYSTEM SCHEME

In this cyclic scheme proposed by Daniel Arnon and his coworkers, Photosystem I takes the energy of sunlight and, through an electron transfer chain (P_{700}—A—Fe-S—Fd—PQ—P_{700}), converts it into ATP, the energy transport molecule in the cell. As the figure indicates, electron transfer produces a hydrogen gradient across the chloroplast membrane (mediated by the electron and hydrogen ion carrier plastoquinone—PQ). The potential energy is used by the enzyme ATPase (CF_0—CF_1) in ATP formation.

The Capture of Light

Daniel Arnon and his coworkers first discovered how light is transformed into chemical energy by chloroplasts in green plant cells through a cyclic process similar to that

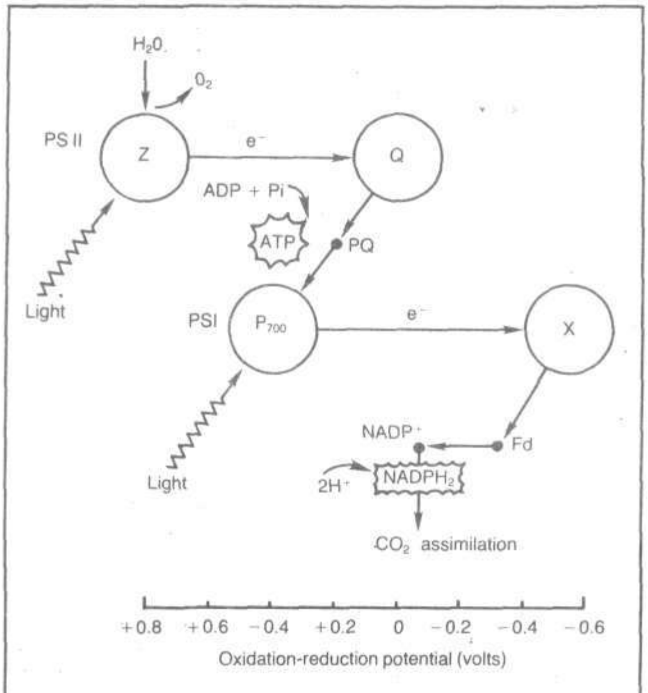


Figure 3
THE Z-SCHEME

The so-called Z-scheme proposes that Photosystems I and II perform complementary functions: The light energy captured by Photosystem II is transferred, by means of quinone and plastoquinone (Q and PQ) to Photosystem I. Photosystem I then transfers the energy to $NADPH_2$, the reducing power molecule, by means of other electron carriers (X, Fd [ferrodoxin], etc.) ATP is formed during this electron transference.

found in photosynthetic bacteria (Figure 2)[4]. They showed that when PS I is excited by light, it gives an electron to an acceptor-donor chain by which the energy transport molecule, ATP, is produced; and at the end of the chain, PS I's electron returns to the pigment molecule (hence, it is a cyclic process).

Arnon and his colleagues subsequently found other noncyclic electron chains that are able to produce ATP and oxygen.[5] These experiments showed that there is one mechanism that is able to break down water (H_2O), taking the electrons and transferring them to an acceptor substance ($NADP^+$) in order to produce reducing power ($NADPH_2$). Through this process, free oxygen (0_2) is also produced.

In an attempt to relate the different properties of both photosystems, other scientists proposed the Z-scheme, which hypothesized that PS I and PS II have complementary functions in producing free oxygen and reducing power from sunlight and water (Figure 3). As noted above, the two photosystems capture light with different wavelengths. The Z-scheme proposed that PS II is able to take an electron from water and give it to an acceptor substance (known as Q), which, by means of an electron transport chain, gives the electron to PS I. PS I is excited by light energy of a different wavelength, and it ejects an electron into another acceptor substance (known as X), giving the electron—also by means of an electron transport chain—to an electron and proton-capturing enzyme, which produces reducing power.

The Z-scheme appears to be very coherent and is popular in scientific circles. However, it assumes several conditions. First, the two photosystems are assumed to exist in approximately the same proportion in the cell. Second, the two photosystems must be nearby spatially. And third, the Z-scheme proposes that ferrodoxin (Fd), an important electron carrier in this scheme, will not be reduced if the electron flow is cut.

A growing body of experimental evidence is at odds with these assumptions. For example, last year, Arnon showed that ferrodoxin can, in fact, be reduced in a way different from that proposed by the Z-scheme.[6] When he inhibited the electron carrier plastoquinone (PQ), cutting the electron flow with the intention of stopping ferrodoxin reduction, the ferrodoxin was reduced anyway.

Anastasio Melis and his colleagues had already shown that the proportions of PS I and PS II in the cell vary.[7] On average, there is three and a half times more PS II than PS I. Jan Andersson and Bertil Anderson have also shown that the two photosystems are located relatively far apart within the chloroplast, such that electron transport would appear to be impossible between the two photosystems.[8]

In 1981, Arnon proposed a noncyclic scheme for photophosphorylation (the production of ATP by means of light energy capture) that suggests an alternative hypothesis about the relationship between the two photosystems.[9] In experiments with chloroplasts he showed that PS II can capture an electron from water and give the electron directly to ferrodoxin without the mediation of PS I. Thus, if there is a relationship between PS I and PS II, it does not appear to be the complementary one hypothesized by the Z-scheme.

According to Arnon, PS II can be excited into different states, having different oxidation reduction potentials.[10] When PS II is highly excited (with a −0.6 oxidation reduction potential), it gives its electrons to the acceptor substance ferredoxine (which has a −0.4 reduction potential). In the other reduction state, PS II performs only the cyclic transference of its electron through plastoquinone (in other words, the electron is returned to PS II).

Scientists have yet to explain how PS II arrives at the two different states indicated in Arnon's noncyclic scheme; however, the answer to this question will explain a great deal about photosynthesis. Arnon's evidence strongly indicated that ferrodoxin can not be reduced by a different electron donor than PS II. PS I cannot permanently give its electron to ferrodoxin because it is not able to take an electron from another donor.

In his latest work, Arnon explains that the presence of PS II redefines PS I. He shows that there does exist a certain relationship between PS I and PS II, whose principal role is probably regulatory. The shared substances of PS I and PS II are key ones for the light capture machineries of both;

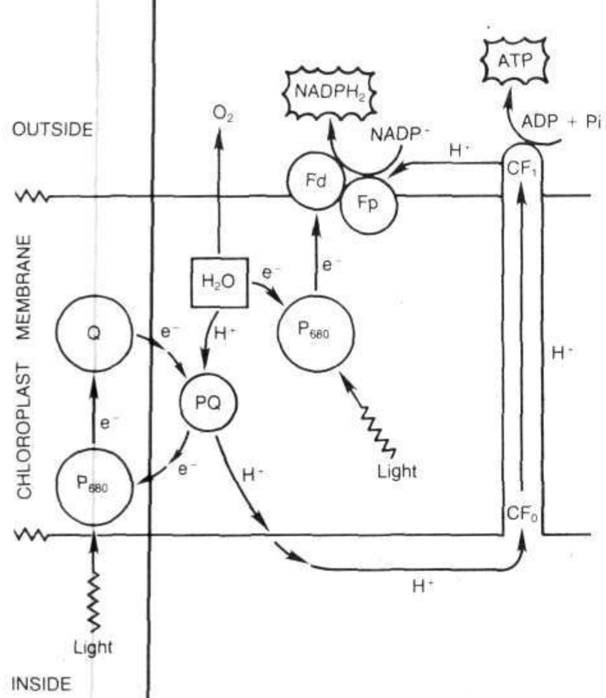


Figure 4
ARNON'S OXYGENIC PHOTOSYSTEM SCHEME
In the photosystem scheme depicted here, Arnon proposes two roles for Photosystem II (P_{680}) alone. One is cyclic (P_{680}—Q—PQ—P_{680}): Hydrogen is transferred through the chloroplast membrane by means of plastoquinone (PQ) to produce ATP by the enzyme ATPase (CF_0—CF_1). The second is linear (P_{680}—Fd—fp—$NADPH_2$): Water is broken down into hydrogen ions and oxygen gas. In the latter, oxygen is produced by Photosystem II alone.

however, these substances play a more efficient role in the more efficient photosystem—PS II.

Most likely, the two photosystems operate not collaboratively in series, as was proposed in the Z-scheme, but synchronously in parallel. Arnon's approach of viewing the two photosystems as basically autonomous, except for possible regulatory connections, excludes the need for a one-to-one stoichiometry between them, as is assumed by the Z-scheme. In Arnon's perspective, the structure and functions of chloroplasts are entirely coherent.

Perhaps the most interesting point about Arnon's new proposal is that it has brought to light the importance of geometrical relations in the chloroplast and also the topological ordering of the pigments critical for photosynthesis.

The Antenna Effect

It has long been recognized that chlorophyll molecules, the light capture pigments of green-plant cells, are not randomly distributed but topologically arranged in the cell. The chloroplast, the specialized organellum in which the chlorophyll is located, has two membranes. The inner membrane is folded forming closely spaced stacks of thylakoid membranes, called grana, which are the principal site of Photosystem II. The grana are connected to one another by single thylakoid membranes, or filaments; and it is within these filaments that PS I is principally located. The chemical substances for light capture in both photosystems are located in the thylakoid membranes. The enzymatic complex for CO_2 capture, and for transforming CO_2 into carbohydrates, is located in the spaces between thylakoid membranes.

The geometrical distribution of pigments was demonstrated many years ago by Emerson and Arnold, in an experiment with a culture of *Chlorella*, a green algae.[11] "The scientists measured the oxygen yield from photosynthesis when *Chlorella* cells were exposed to light flashes lasting a few microseconds. They expected to find that the yield per flash would increase up to the point that each chlorophyll molecule absorbed a photon (which was used to produce ATP and $NADPH_2$). However, they instead found that the maximum oxygen yield occurred when one out of 2,500 chlorophyll molecules had absorbed a light quantum during the flash. These 2,500 molecules were named a photosynthetic unit and the phenomenon the Antenna Effect, an allusion to the electromagnetic wave concentration effect on one molecule by all the others.

The Antenna Effect is significant in that it reflects the topological ordering process at work in photosynthesis. There are no chemical differences between the chlorophyll

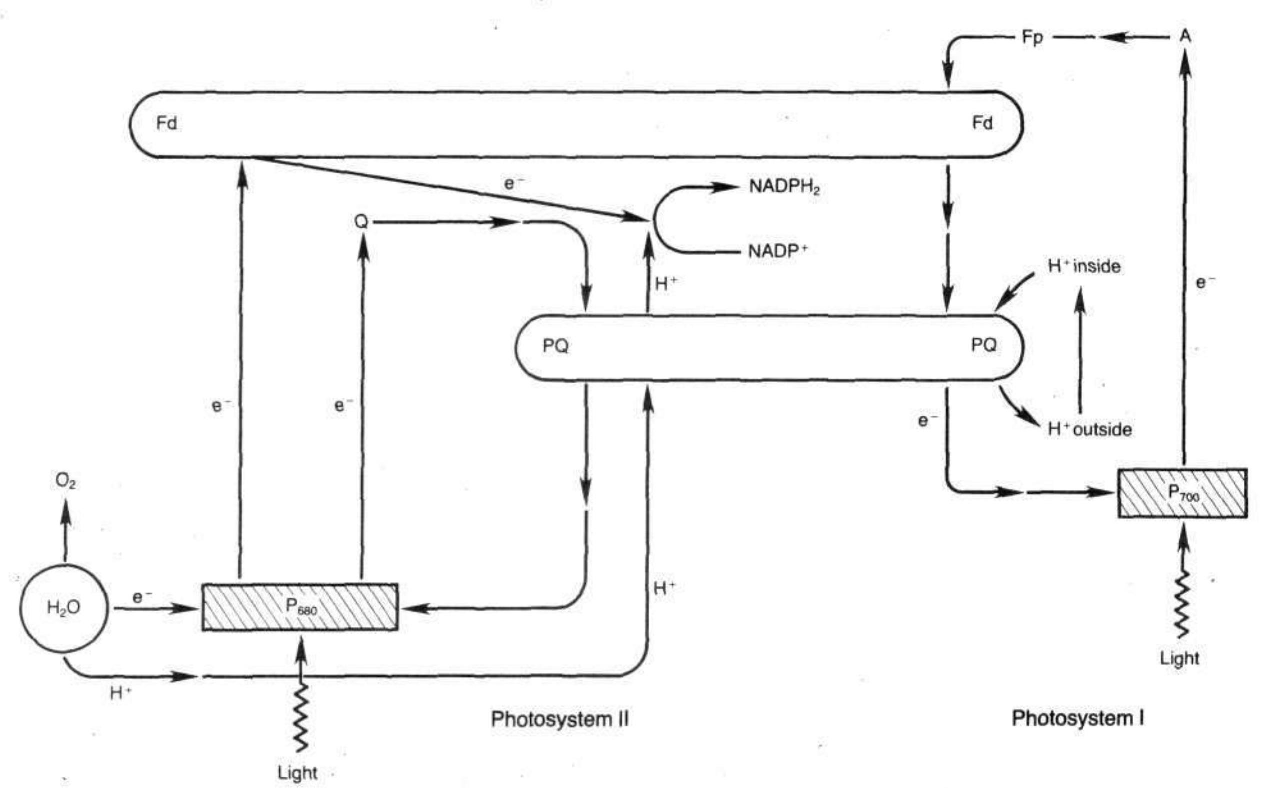


Figure 5
THE PS I-PS II RELATIONSHIP: ARNON'S NEW HYPOTHESIS

Arnon's latest work indicates that there is a certain relationship between Photosystems I and II, whose principal role is probably regulatory. This regulatory function may be performed by the electron transporters that are shared by both photosystems (Fd and PQ).

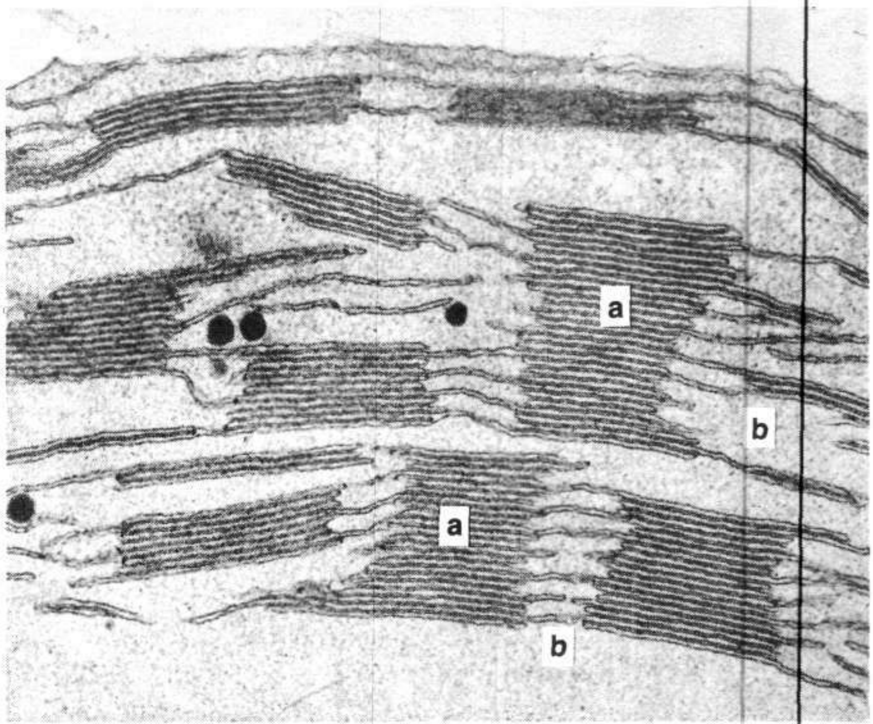


Figure 6
THE CHLOROPLAST MEMBRANE
The distribution of the light-capturing pigments of green-plant cells is not random but topological. The thick stacks of thylakoid membranes (a), called grana, are the main site of Photosystem II. It is here that light capture is carried out by chlorophyll and other pigment complexes. Photosystem I is located principally in the thinner part of the membrane (b).

molecule that is excited and all the rest in the photosystem; the only difference is its geometric position in the photosynthetic unit. Students of photosynthesis have still to answer many remaining questions about the observed effect—for example, what is the position of the chlorophyll molecule that is excited? What causes the phenomenon? Does it make photosynthesis more efficient?

The most widely accepted hypothesis about the Antenna Effect is that light is absorbed by hundreds of chlorophyll molecules in a photosynthetic unit, which then transfer their excitation energy to the site, known as the *reaction center*, at which the chemical reactions involved in ATP and $NADPH_2$ formation occur.[12] This hypothesis has given rise to important experimental work on the question of energy transfer between pigments—even if the hypothesis leaves unanswered many questions about the effect, such as the difference between the hundreds of chlorophyll molecules in the chloroplast and the one in the reaction center.

Quantum Transfer Between Pigments

One observed feature of the light-collecting systems of photosynthesis is the transference of quanta of light from pigment to pigment (this property was discovered through fluorescence measurements—the emission of light in the ultraviolet range when an atom or molecule has been excited by energy). It has been shown experimentally that a quantum of light can pass from one molecule to a neighboring molecule, as long as the partners are sufficiently close to one another—as is the case in the thylakoid membrane in the chloroplast. Such transference by inductive resonance allows the quanta to "visit" several hundreds of molecules in the photosynthetic unit during a very short time (5×10^{-9} seconds).[13]

Transference of this sort has been found not only between similar molecules but between different pigments. For instance, when a pigment is excited it emits light; if the neighboring pigment can absorb light at this wavelength, the neighboring pigment will also be excited. In experiments in which chlorophyll *a* and *b* are in solution, and the solution is irradiated with a wavelength that excites mainly chlorophyll *b*, the fluorescence of chlorophyll *a*, not chlorophyll *b*, has been observed. Chlorophyll *a*, with its slightly lower excitation level, takes the energy from chlorophyll *b*.[14]

The energy from sunlight is deposited in the reaction center, and when the chlorophyll molecule is excited it gives its electron to an acceptor. The transport of this electron across an electron transport chain allows the entry of hydrogen ions into the thylakoid membrane of the chloroplast, creating a hydrogen ion gradient across the chloroplast membrane. The accumulated energy (arising from the difference in electrical potential on the two sides of the membrane) is transformed into chemical energy by means of the enzyme ATPase, which is held within the chemical bonds of ATP. The ATP molecule performs its "energy transport" role, releasing its energy wherever it is needed in the cell.[15]

As we have seen, ATP is present not only in photosynthetic cells, but in all cells—the only difference being the energy source from which it is produced. The fermentative organisms produce the ATP molecule by means of breaking down organic nutrients; respiratory organisms produce ATP by oxidizing organic nutrients, with a much higher yield of ATP produced per organic nutrient consumed than fermentative organisms.

The electron transported by the electron carrier chain is taken by an enzyme and put together with the hydrogen ions (H^+) and $NADP^+$. The resulting compound, $NADPH_2$, is able to give its hydrogen atoms wherever the cell needs them to reduce substances in its metabolism. Thus, $NADPH_2$ is the reducing power molecule of the cell. The efficiency of the technology depends on the amount of net energy produced. Hence, photosynthesis, which is able to produce both ATP and reducing power from the same energy source—sunlight—is a more efficient technology than fermentation or photosynthesis in bacteria.

Biochemical Control of Photosynthesis

We have reviewed the process of light capture and its transformation into the stable energetic compounds ATP and $NADPH_2$. How can the cell use this energy to form carbohydrates from CO_2?

Unlike the light capture process, the carbohydrates are manufactured by means of an enzyme complex. Although enzyme activity is still only partially understood, we can characterize an enzyme as a protein that allows the formation of a cellular compound using less energy than would be required to form the same compound by inorganic means—without life.

CO_2 capture is accomplished through the enzyme complex RuDP, which takes the CO_2 molecule and a five-carbon molecule, forming an intermediary compound that immediately breaks down into two small molecules of three carbon atoms each (phosphoglyceric acid). The latter are precursors of glucose. The oxidized CO_2 molecule is reduced through an enzymatic reaction chain—the Calvin cycle—using ATP and $NADPH_2$. For every six molecules of CO_2 that enter the Calvin cycle, one glucose molecule is formed.

When the concentration of CO_2 is high, the enzyme performs the Calvin cycle activity, and glucose is produced. However, in high concentrations of oxygen, which exist when the light capture process is activated, the enzyme changes its function: It takes the above-mentioned five-carbon molecule (rubulose diphosphate) and breaks this type of molecule into two small ones. One of them goes into the Calvin cycle; the other crosses the chloroplast membrane and is oxidized, forming water and CO_2, and producing ATP. This process is known as photorespiration.[16]

The proportion of photosynthetic to photorespiratory activity is a key factor in the net incorporation of CO_2 and hence in the efficiency of photosynthesis in plants. When light capture is proceeding very fast, producing a large amount of oxygen, the key enzyme, RuDP, performs more photorespiration than photosynthesis; therefore, the rate of CO_2 capture is slowed down and, as a consequence, so is carbohydrate synthesis.

Among higher plants, there are some that photosynthesize more efficiently than others; these are the angiosperm plants, which include sugar cane, most tropical grasses, and maize. More advanced evolutionarily, these plants have a special tissue whose cells capture CO_2 in a different way using a three-carbon molecule (phosphoenol pyruvic acid). This molecule forms a four-carbon compound with the captured CO_2; hence, the plants are known as C_4 plants. The four-carbon molecule crosses the membrane of this special tissue cell and enters the neighboring cell, which is equipped with the Calvin cycle enzyme.

Because of the topological disposition of the tissue in the angiosperm plants, the regulatory Calvin cycle enzyme does not come in contact with oxygen production. And for this reason, its almost exclusive activity is photosynthesis, and it therefore synthesizes carbohydrates more rapidly. The enzyme of the specialized tissue of the angiosperm plants has no regulatory activity to perform (photorespiration/photosynthesis), and its affinity for CO_2 is high. The additional mechanism found in the angiosperms, the three-carbon-molecule way known as the Hatch-Slack pathway, makes CO_2 capture more efficient in C_4 plants than in C_3 plants.

Genetic Control of Photosynthesis

The history of plant life has been characterized by the evolution toward more photosynthetically efficient plants. Now, with genetic engineering, man has the capability to improve the photosynthesis of the less efficient existing plants, for example, by modifying the enzyme in the Calvin cycle to perform photosynthesis alone—as in C_4 plants. This opens up the prospect of improving the photosynthetic mechanism of cereals, vegetables, and other food plants (which are C_3 plants) and greatly increasing their yields.

Over the long term, genetic engineering may be able to be used to improve the light-capture process, enabling plant cells to capture light of different wavelengths than at present. This application of genetic engineering holds great promise for enabling plants to grow and to evolve in the environment of space.

Delia Arujo de Lozano, a biochemical engineer who works with the Fusion Energy Foundation in New York, formerly taught the biochemistry of microorganisms at the National Polytechnical Institute in Mexico City.

Notes

1. See G. Gottschalk and J. Terhard, "Chemiolithotropic and Phototropic Metabolism," *Bacterial Metabolism* (New York: Springer-Verlag, 1980), pp. 225-249.
2. Ibid.
3. J. Bonner and J.L. Varner, "Photosynthesis: The Path of Energy," *Plant Biochemistry* (New York: Academic Press, 1978), pp. 861-870.
4. D. I. Arnon, M. B. Allen, and F. R. Whatley, "Cyclic Photophosphorylation," *Nature* 174: 394.
5. D. I. Arnon, "Role of Light in Photosynthesis with Biographical Sketch," *Scientific American* 203 (November 1960): 50.
6. D. I. Arnon, H. Y. Tsujimoto, and M. S. George, "Proton Transport in Photooxidation of Water: A New Perspective on Photosynthesis," *Proceedings of the National Academy of Science USA* 78: 2942-2946.
7. A. Melis and J.S. Brown, "Stoichiometry of System I and System II Reaction Centers and of Plastoquinone in Different Photosynthetic Membranes," *Proceedings of the National Academy of Science USA* 77: 4712-4716.
8. Andersson, B. and Anderson, J.M. (1980) *Biochim. Biophys. Acta*, 593, 427-440.
9. T. H. Maugh, "A New Light on Photosynthesis," *Science* 213: 994-996.
10. Authorized personal communication (1982).
11. R. Emerson and W. Arnold, "A Separation of the Reactions in Photosynthesis by Means of Intermittent Light," *Journal of General Physiology* 15: 391-398.
12. N. K. Boardman, "The Photochemical System of Photosynthesis," *Advanced Enzymology*, vol. 30, 1:80. no. 1, p. 80.
13. J. Bonner and J. L. Varner, "Photosynthesis: The Path of Energy," *Plant Biochemistry* (New York: Academic Press, 1978), pp. 853-856.
14. Ibid.
15. See P. Mitchell, "Coupling of Phosphorylation to Electron and Hydrogen Transference by Chemi-osmotic Type of Mechanism," *Nature* 191: 144-148.
16. See R. M. Devlin and A. V. Barker, "Photorespiration," *Photosynthesis* (New York: Van Nostrand Reinhold, 1971), pp. 181-213.

It is likely that the P-450 detoxification enzymes, which are present in all living organisms including bacteria, evolved very early as a crucial step in evolution.

Detoxification Enzymes and Evolution

by Ned Rosinsky, M.D.

AN ESSENTIAL FEATURE of evolution is the ability of organisms to protect themselves and thrive within an immensely diverse chemical environment. There are some 100,000 small and medium-size chemicals in varying concentrations present in nature, a significant portion of which are poisonous to living cells and must be eliminated from cells if they are to survive. The environmentalists who see chemical pollution from industry everywhere threatening living organisms are ignorant not only of the natural condition of the biosphere—chemical diversity and toxicity—but of this basic capacity of living organisms to cope with toxic chemicals.

A group of enzymes known as the P-450 series, which are present even in primitive bacteria, plays a crucial role in this process. Possibly numbering in the hundreds or thousands, these enzymes protect the organism against the toxic chemicals by converting them to harmless substances. The P-450 enzymes thus allow organisms to exist in a widely diverse environment; the organisms are *stabilized*. At the same time, these enzymes allow organisms greater freedom to exist in a variety of environmental conditions that would otherwise be too chemically hazardous: The enzymes open up new ecological areas and lay the basis for evolution or *change*. As in many aspects of biology, stability and change are closely linked; for example, DNA must be understood as crucial for both stable inheritance and evolutionary development.

The P-450 enzymes also allow for increased population densities by enabling organisms to tolerate better the wastes produced by other organisms. These waste products and the breakdown products of dead organisms become, in fact, a major source of toxic chemicals in the environment as evolution advances and the biosphere becomes more populous. The enzymes also improve the efficiency of ecologies since they allow some toxic chemicals to be converted to nutrients, again serving to increase the population density potential. The P-450 group and similar enzymes may ultimately have allowed the evolution of multicellular ogranisms as the extreme form of the single-cell population-dense condition. The evolution of the P-450 group itself is an interesting question in genetics, as advanced organisms may have the genetic capacity to produce hundreds or thousands of forms of this enzyme group.

In the last two decades, the P-450 enzyme group has attracted clinical interest because it also appears to be related to cancer, a disease characterized by a dedifferentiation of cell type, as well as a breakdown in the control of cell growth. Both high and low rates of P-450 production have been associated with individual differences in susceptibility to chemical carcinogens. Thus, further investigations of the dynamics of the P-450 enzyme system may provide some insight in this area.

What Is a Poison?

To understand the work done by the P-450 enzymes we must first examine what a toxic chemical is. Generally speaking, toxic chemicals are those chemicals that interfere with the normal functioning of the organism in any way. For instance, some substances dissolve in and accumulate in the cell membrane and interfere with its functioning as the regulator of what comes into and goes out of the cell. Other substances combine with enzymes and interfere with their normal functioning, disrupting metabolism or other cellular activities. In the latter case, the toxic chemical frequently resembles chemically the metabolite that the enzyme acts on. These toxic substances are often the waste products of other living organisms or the breakdown products of dead organisms.

For the most part, however, since most of the medium and small-size chemicals exist in relatively low concentrations in the environment, they do not cause problems, as long as they do not accumulate in the cells. An important factor determing if a substance will accumulate or not is whether it is fat- or water-soluble. Water-soluble substances can enter the cell easily, but they are also washed out easily and do not generally accumulate in the cell; whereas fat-soluble substances do tend to accumulate.

This property of fat or water solubility depends on a specific chemical property of the substance: the degree of imbalance of the electrical charge within the molecule, known as the polarity of the molecule. Water molecules are polar, each molecule having a positive end and a negative end. Since opposite charges attract, the molecules tend to interact strongly with one another. If a polar chemical comes in contact with water—which comprises most of the biosphere, including the oceans, lakes, soils, and even humid atmosphere, as well as 90 percent of cell cytoplasm—it is attracted to the liquid and dissolves in it.

Oil, by contrast, is made of organic molecules composed of carbon and hydrogen in which the electrical charge is more symmetrically arranged in the molecule; there is no positive or negative end. Nonpolar molecules do not interact with water, although they can dissolve in oil because of the weaker interactions among the nonpolar oil molecules.

Living cells consist of both water and oil-type components. The water phase consists mostly of the cytoplasm, the liquid portion of the cell contained by the cell membrane. The cytoplasm is more than 90 percent water, also containing dissolved minerals such as potassium, sodium, and calcium, many small and medium-size chemicals, and many proteins that serve as catalysts (enzymes) for metabolic chemical reactions.

The cell membrane and other important membranes within the cell are composed primarily of lipid molecules. These are long molecules that are almost completely nonpolar except at one end, thus combining both nonpolar and polar qualities in different parts of the molecule (Figure 1). A familiar example of this type of substance is soap, which removes oily dirt by acting as a "go between," interacting with both the oil and water to allow the dirt to mix with water so that it can be washed away. In the cell membrane, the lipid molecules are oriented so that the nonpolar portion is directed into the membrane, while the polar portion is directed toward the surface of the membrane (Figure 2).

The cell membrane must have developed very, very early in the origin of life to prevent the loss of polar substances from the cell by inhibiting their passage through the lipid layer. But because of its oil-type components, it has from the beginning presented a problem as an avid "sponge" for various organic chemicals in the environment. Keeping the membrane "clean" must have been one of the earliest hurdles in the evolution of primitive life forms.

Today even the most primitive organisms have an enzyme system for this function, the P-450 enzymes. In addition to handling external poisons, the P-450 group is involved in the metabolism and elimination of some of the cell's own waste products.

The P-450 Enzymes

Enzymes are specialized proteins that catalyze, or enormously speed up, chemical reactions in living cells. Each cell has thousands of different enzymes, and each type of enzyme is specific to one or at most several chemical reactions. The enzymes perform such functions as breaking down nutrient molecules; transferring energy from these nutrients to ATP (adenosine triphosphate), the "energy currency" molecules of the cell; and using ATP and the breakdown products of nutrients to build up normal components of the cell such as proteins, DNA, and membrane lipids.

The P-450 group of enzymes are oxidizers, or monooxygenases; that is, they function by inserting one atom of oxygen into a molecule, thus oxidizing it. Unlike those enzymes that oxidize nuitrients such as sugar to produce energy for the cell, the P-450 enzymes aid the organism in eliminating toxic chemicals by transforming fat-soluble substances, those that tend to accumulate in the cells, into water-soluble substances. As noted above, water-soluble molecules, because of their polarity, or imbalance of electrical charge, are easily dissolved and eliminated from the cell.

The P-450 enzymes attack oil-soluble substances and partially oxidize them as the first step in making them water soluble. After the oxygen atom is added to the molecule, a second enzyme uses the oxygen as a target to add a polar molecule. The newly synthesized molecule is now polar enough to be easily eliminated from the cell.

The P-450 enzymes were first discovered in the 1950s by biochemists investigating monooxygenase activity. A decade later, pharmacologists investigating the breakdown and elimination of the drug phenobarbital discovered that phenobarbital induces a more than 10-fold increase in an enzyme produced by the liver that oxidizes the drug molecule and sets the stage for a second reaction, resulting in the increased water solubility of the molecule and its elimination in the urine through the kidneys. In fact, treatment with pharmaceuticals depends on the existence of such enzymes, which break down the drug molecule usually within several hours, and thus allow the physician to control the therapy by the rate he administers the drug.

During the same period, another potent stimulator of liver P-450 enzyme activity was discovered, benzopyrene, a

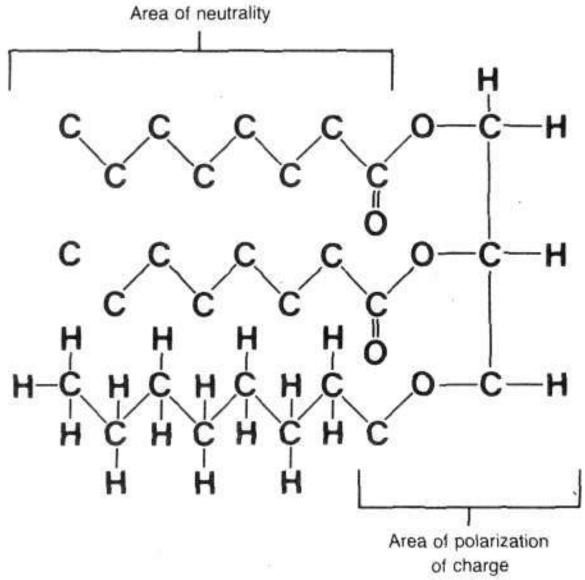


Figure 1
SCHEMATIC OF A LIPID MOLECULE

The lipid molecules found in the cell membrane are for the most part electrically neutral—that is, their positive and negative charges are evenly balanced for the molecule as a whole. At the right end, however, there is a local imbalance of charge, one portion being positive and another nearby area being negative. This area of imbalance interacts strongly with water, since water molecules are themselves strongly electrically imbalanced, or polarized. In the schematic, C stands for carbon atoms, H for hydrogen, and O for oxygen.

strongly carcinogenic polycyclic hydrocarbon (a carbon-hydrogen compound in which the carbon is arranged in closed rings). The enzyme it induced was found to be different from the phenobarbital-induced P-450 enzyme.

Since that time, dozens of other inducers of monooxygenase activity have been found, which induce yet other enzymes of the same class. These inducers include caffeine, ethanol, methadone, volatile deodorants, camphor, styrene, wood terpenes, estrogens, and many pharmaceuticals such as the antibiotic rifampin.

Although there appear to be many forms of P-450 enzymes, there are also numerous cases of overlap in specificity of chemical reaction. For example, the enzyme induced by phenobarbital can also act in the metabolism of vitamin D. The total list of substances now known to be oxidized by the P-450 group is enormous. It includes most drugs; soap and deodorant ingredients; polycyclic hydrocarbons found in smog, charcoal-cooked foods, and cigarette smoke; naturally occurring and synthetic steroids (including the body's own sex hormones); strong mutagens such as N-methyl-N'-nitro-N-nitrosoguanidine; and many endogenous substances such as thyroid hormone and fatty acids. Red wine has at least 300 to 400 chemicals that are synthesized and broken down by P-450 enzymes.

Some researchers in the field now believe that there are probably hundreds if not thousands of kinds of P-450 enzyme, each with specific, though possibly overlapping, chemical specificity. The enormity of this class seems to be eclipsed only by the immune system, which is capable of producing several million different antibodies in response to different foreign proteins, frequently in the context of an invading microorganism.

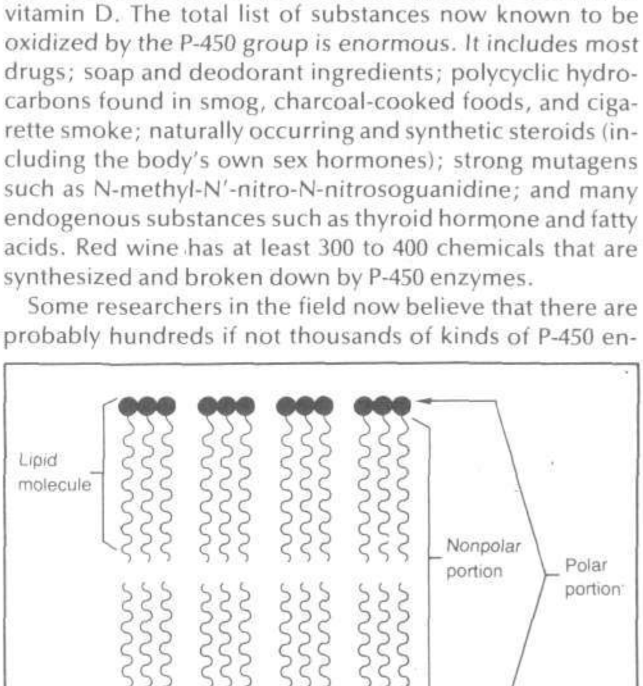


Figure 2

CROSS SECTION OF A CELL MEMBRANE SEGMENT

The cell membrane is composed of a double layer of lipid molecules, which are perpendicular to the surfaces of the membrane. In this schematic, the inside of the cell is at the top of the diagram and the outside of the cell is at the bottom; the polar ends of the molecules face out of the membrane in both cases. These polar ends are strongly attracted by the water molecules outside and inside the cell, while the nonpolar ends of both layers of the membrane create an area in which fat-soluble substances can dissolve. It is in this area that many of the fat-soluble toxic chemicals accumulate and cannot be easily washed out. It is also in this area that the P-450 enzymes act to chemically change the fat soluble toxins into water-soluble substances that can be eliminated from the cell.

The Genetics of the P-450 Group

The possibility of such diversity raises interesting questions about the genetic coding of the P-450 enzymes. Dr. Daniel W. Nebert of the National Institutes of Health for more than 15 years has been investigating P-450 genetics, beginning with a study of an abnormal strain of mouse that is not responsive to P-450 induction.[1] Nebert and colleagues have found that this abnormal mouse strain lacks a certain protein acceptor molecule that, in the normal strain, combines with the inducing substance—benzopyrene, for example. In the normal strain, this complex then moves into the cell nucleus, and shortly thereafter, the new P-450 is produced.

What happens inside the nucleus is still a mystery. Are there thousands of genes for the P-450 group, one for each form of the enzyme, or is some other genetic system involved? How are the genes activated and deactivated? Why are some forms of P-450 produced only by embryos and others only by adults in response to the same chemical? Although the one-gene-one-enzyme hypothesis appears to work for bacteria (and even there some major problems arise), the functioning of genes in advanced organisms is still very poorly understood.

In order to generate some hypotheses about the genetics of the P-450 group, Nebert has compared these enzymes to the immune system, which although also poorly understood is further along in investigation.

In the case of the immune system, each antibody molecule is actually made up of four protein molecules, consisting of two identical pairs. Each pair in turn consists of a heavy and a light protein, and each of these contains a constant portion—the same for all antibodies—and a variable portion—specific for the individual antibodies. Many researchers believe that the total variation of antibodies is produced by combinations of these two variable areas; for example, a million different antibodies could be produced by combinations of a thousand kinds of one portion and a thousand kinds of the other portion.[2] This hypothesis decreases the total genetic content required from 1 million to 2,000 genes, but makes the genetic activity more complex.

It is known from experiments with mice that the genes for the heavy and light portions of the antibodies do, in fact, exist in hundreds of copies on the chromosome, and that some variation exists in these copies. Is this variation within the chromosome the same as the final variation of the antibodies? Is this variation inherited in its entirety, or is it wholly or partially generated during the embryological development of the organism? Even if such diversity exists at the genetic level, how does the cell determine which genes to activate in response to a foreign protein? It is known that while the antibodies are produced by certain white blood cells called plasma cells, other immune cells, the T-lymphocytes, are involved in the initiation of the antibody response. The T-lymphocytes have a surface protein that combines with the foreign protein, and the message is then transmitted to the plasma cells. The plasma cells then start to produce the correct antibody.

Many investigators think that the plasma cells differentiate during embryology so that by birth there are several thousands with the potential to produce each of the millions of possible antibodies, and thereafter each plasma cell is *committed* to producing *only one* antibody. This hypothesis suggests that the T-lymphocyte receptor molecule is, in fact, the antibody itself. After combination with the foreign protein, the T-lymphocyte is activated. It seeks out those plasma cells that are producing its unique antibody and induces them to proliferate vastly and in turn to produce large amounts of their antibody.

Antibodies also have overlapping specificities. Frequently, the initial response to an invading organism involves several antibodies with partial specificity. This is followed by progressively more specific responses over a several day period.

The hypothesis outlined here explaining antibody activity, that millions of types of antibodies are produced in advance and are merely awaiting stimulation by foreign substances, may seem reductionist, but it is still plausible. The situation with the P-450 enzymes is even more demanding, however, involving a more active genetic response to unique new foreign substances, possibly chemicals that no organism has yet encountered. Nearly all the P-450 enzymes are produced by the same liver cells, although every cell type in the body can produce some of the P-450 enzymes. Thus, the specificity for producing a particular P-450 enzyme cannot lie in some random commitment of a particular liver cell at birth, but must be actively induced again each time a new substance enters the liver cell.

Further Research

The major problem in approaching the genetics of the P-450 group is that genetic regulation in advanced organisms is not at all understood at present. For example, probably 90 percent of the DNA in chromosomes does not code for proteins but has some other unknown function. Many of the DNA sequences that do code for proteins are interrupted part way through by extending noncoding DNA, whose function is unknown. The actual geometry of the double-stranded DNA in the chromosome, its tertiary foldings, and so on, is all unknown, though it is likely that this higher-order geometry is involved in genetic expression.

These areas are poorly understood for several reasons. First, the major techniques for investigation currently available are biochemical: the extraction of chemicals such as DNA or proteins, followed by purification, and then characterization by chemical or physical means, such as by X-ray diffraction of crystals of the substance. These techniques are not possible if what is being studied is too large. A chromosome cannot be crystalized, and if the DNA is extracted from it, its higher-order structure is changed.

The analysis of the P-450 enzymes involves similar problems. These enzymes are themselves oil soluble and lie deep within the membranes of the cell. If they are removed by disrupting the membrane with detergents, they are

NIH

Dr. Daniel W. Nebert in his laboratory at the National Institute of Health. The abnormal mouse strain that he is investigating lacks a protein acceptor molecule.

changed so profoundly that it is impossible to determine their original structure.

What is needed is a better diagnostic probe, a more powerful microscope with which to examine these substances. The government laboratories are now developing an X-ray microscope that may be able to take a "picture" of one chromosome with resolution at the atomic level.[3]

A second kind of probe will be produced by another new technology: the production of pure forms of a single gene by recombinant DNA. If one pure form of a P-450 is obtained, the gene can then be used to cross-react or hybridize in other organisms to see if they have that specific form of P-450 gene. The gene for one kind of P-450 could also be used to separate out that kind from a mixture of P-450 genes, whose proteins are currently inseparable by ordinary chemical means since they are so similar to one another.

Aside from new technologies, what is needed is an entirely new conceptual approach to unravel the mystery of genetic expression. The developing embyro proceeds through an orderly series of unfolding geometries whose boundaries and other geometric aspects determine the ongoing developmental patterns. This geometric approach has so far been the only one that has explained anything at all about how differentiation of form takes place, in particular in the nervous system and in the growth of limbs.[4]

The metabolic pathways likewise consist of an interconnected network that "hangs together" much like a network in an actual physical continuum, and is subject to the same kinds of instabilities and wave propagation as a compressible fluid. It is in this higher-order context that the genes operate, and it may well be that they operate along similar principles, particularly with regard to expression, but also possibly with regard to actual DNA code changes, especially in the case of the great variability of the immune and P-450 systems. An important line of research is the investigation of permanent effects on organisms' P-450 enzymes of exposure to toxic chemicals before birth, as this may shed light on how genes are irreversibly activated or deactivated in the course of embryological development.[5]

Any major decrease in the functioning of the immune system, such as poisoning with certain drugs, results in a general increase in cancer rates. Similarly, individual differences in inducibility of P-450 are also associated with changes in cancer potential. For example, animals that have high rates of P-450 induction in response to certain polycyclic hydrocarbons are more susceptible to cancer when exposed to these substances. Presumably, the enzyme creates large amounts of the oxidized chemical, and before the second step reaction takes place, this chemical can readily react with many other cell molecules, including DNA. The oxidized molecule is actually much more reactive than the original molecule, and this may explain many of the individual differences in response to carcinogens.

This geometric approach to embryology and differentiation could be especially relevant to the P-450 and immune systems since both are involved in cancer, which is characterized by cell dedifferentiation, or loss of specialization; for example, cancers of muscle cells, skin cells, gland cells, and other specialized cells progressively lose their special attributes such as contraction and secretion.

If embryological geometries are crucial to differentiation, then cancer involves an undoing of what these geometries set up; in cancer there is a loss of control of cell division and a dedifferentiation of cell type, as well as a breakdown in the cell-to-cell cohesion essential for tissue formation (whose absence is involved in the process of metastasis of cancer). Thus, an understanding of the role of these geometries is central to understanding cancer. Granted, the geometries may in turn affect genetic regulation through certain chemical mediators, and intervention to prevent or cure cancer may involve these mediators. Yet to identify these mediators in the first place would involve understanding the differentiation-related geometries as signposts for where to look.

P-450 and Evolution

The P-450 system includes many enzymes that are involved in normal metabolism, such as the elimination by oxidation of steroid hormones, thyroid hormones, and fatty acids. This raises the question of whether the current large number of P-450 enzymes, which are involved in elimination of foreign as well as endogenous substances, is derived evolutionarily from original enzymes that were involved in normal metabolism; or whether the reverse is possibly the case—the enzymes for detoxifying endogenous substances are derived from enzymes for foreign substances.

On the basis of general characteristics, it is currently presumed that the P-450 enzymes are all fairly similar molecules, differing, as do the antibodies, at the so-called active site of chemical reaction. There are many known enzyme families that basically do the same thing, such as "add X," but the different members of a family act on different molecules. It is presumed that because there are strong structural similarities within such families of enzymes, each family is derived by small genetic changes from one ancestral enzyme.

A second evolutionary aspect is that some metabolites of the P-450 enzymes, such as the fatty acids, not only can be eliminated after the second step reaction, but also can be further oxidized and used as a nutrient source.[6] Thus the detoxification of a noxious substance may eventually lead, though evolution, to the use of that substance as a nutrient. What is harmful and what is beneficial to an organism become flexible categories, with enzyme evolution mediating the shift. Likewise, more metabolic pathways (in more advanced metabolism) increase the basis for responding to more diverse toxic chemicals.

The protection of organisms from toxic chemicals has the ecological significance noted earlier. It allows for the increased density of populations, since organisms can tolerate the wastes produced by others better, permitting ultimately the evolution of multicellular organisms. Similarly, the advanced development of the nervous system requires large densities of electrically active membranes as well as insulator membranes. The human brain has the highest fat content of any body tissue other than storage fat. Such an organ would be "unthinkable" without an efficient clearing mechanism for fat-soluble toxic chemicals. The same holds true for the "brains" of even primitive multicellular organisms, even if they are simply small clusters of nerve cells.

The development of the P-450 enzymes, which provide such a clearing mechanism, is thus probably linked to the most central questions of evolution.

Ned Rosinsky is a practicing physician in New York City who works with the Fusion Energy Foundation.

Notes

1. R.R. Hannah, D.W. Nebert, and H.J. Eisen, "Regulatory Gene Product of the Ah Complex," *Journal of Biological Chemistry*, vol. 256 (1981), pp. 4, 584-90.

For further reading, see the extensive published papers of D. W. Nebert, et al. including "The *Ah* Locus, a Multigene Family Necessary for Survival in a Chemically Adverse Environment: Comparison with the Immune System" *Advances in Genetics*, vol. 21 (1982); "Genetic Mechanisms Controlling the Induction of Polysubstrate Monooxygenase (P-450) Activities," *Annual Review of Pharmacological Toxicology*, vol. 21 (1981), pp. 431-62; and "Multiple Forms of Inducible Drug-metabolizing Enzymes: A Reasonable Mechanism by Which Any Organism Can Cope with Adversity," *Molecular and Cellular Biochemistry*, vol. 27, no. 1 (1979), pp. 27-46.

2. J. Schilling et al., "Amino Acid Sequence of Homologous Antibodies to Dextran and DNA Rearrangements in Heavy Chain V-region Gene Segments," *Nature*, vol. 283 (1980), p. 35.
3. A. Robinson, "High-resolution Imaging with Soft X-rays," *Science*, vol. 215 (1981), pp. 150-2.
4. E.L. Schwartz, "The Development of Specific Visual Connections in the Monkey and the Goldfish," *Journal of Theoretical Biology*, vol. 65 (1977), P. 655. Schwartz shows that the distortion of the visual image as it is carried back from the eye to the brain is related to the way the vision area of the cortex—the boundary condition—determines the shape of the optic nerve bundle. The distortion of the image is part of the mechanism that allows a viewer to recognize an object as constant while it is moving away from or toward the viewer or turning.
5. See for example, R. A. Faris and T.C. Campbell, "Exposure of Newborn Rats to Pharmacologically Active Compounds May Permanently Alter Carcinogen Metabolism" *Science*, vol. 211 (1981), pp. 719-21; and W. Levin, et al., "Neonatal Imprinting and the Turnover of Microsomal Cytochrome P-450 in Rat Liver," *Molecular Pharmacology*, 11 (1975), pp. 190-200.
6. I. Kosuke et al., "Omega and (Omega-1)-hydroxylation of Fatty Acids in Rabbit Intestinal Mucosa Microsomes," *Microsomes, Drug Oxidation, and Chemical Carcinogenesis*, vol. 11 (1980), pp. 729-33.

BNF: The Prospect for Biofertilizers

An Interview with Dr. N.S. Subba Rao

Biotechnology is a term coined only recently. How would you define it, and how would you situate the work you do as a microbiologist within this framework?

Biotechnology can be defined as the ways and means of generating man's increasing needs by genetically altered microorganisms and living cells at a rate much faster than what is being done today. Qualitatively as well as quantitatively, biotechnology encompasses all aspects of human endeavour—industry, agriculture, human welfare, environment and so on.

When the Romans were intoxicated in 6000 B.C. with a broth fermented out of a concoction of grains, the art and science of microbial fermentation began. In a sense the seeds of biotechnology were then sown. The sudden realization of the value of biotechnology as a potential tool to meet human necessities was the result of the "energy crunch" which is being currently experienced by both the "haves" and "have nots." The realization that fossil fuels are being depleted at a very fast pace has made us pay more attention to renewable resources of energy. The emergence of biotechnology is a part of this major energy problem, and the solution is to speed up the normal processes of producing the end products from nature such as food, feed, plant nutrients and protectants, pharmaceuticals and super drugs through less energy consuming processes.

Agriculture is the mainstay of developing countries like India. The magic seeds of high yielding wheat and rice produced by plant breeding techniques can perform well at high levels of NPK fertilizers. Whe they were developed and used, the pressure on fossil fuel, the raw material needed for nitrogenous fertilizer production, was not great. Bountiful harvests were realized which helped to overcome food deficits and shortages. Today the situation has changed because fertilizer production is insufficient and more factories cannot be installed overnight to meet the demands of increased acreage on the farm. The greater availability of irrigation has also created a demand for more fertilizers. It is in this context that nature's vast reservoir of elemental nitrogen (75 percent volume) serves as an inexpensive, less energy consuming and renewable resouce for partially meeting the N-requirements of crops.

There are several nitrogen fixing microorganisms which live freely in nature as well as inside the plant cells in specialized structures called "root nodules." They possess an enzyme syst..n called "nitrogenase" which is controlled by a cluster of 17 genes known as "nif" genes. The enzyme combines nitrogen and hydrogen to form ammonia. Today, the estimates are that legumes convert atmospheric nitrogen in root nodules at the rate of 20-35 x 10^6 tons/year and legume fixation is at least one half that of industrial fixation.

The global figure for population was 4374 million in 1980 and will probably reach 6253 million by 2000 AD. We would then require 2600 million tons of cereals and 520 million tons of grain legumes as human food, for which the consumption of factory made NPK mineral fertilizer has to increase from 113 million tons in 1980 to 307 million tons in 2000 AD. The world's demand for nitrogen alone will rise from 56 million tons in 1980 to 140 million tons by about 2000 AD, a production increase of about 90 million tons.

To meet this challenge, resources from developing nations are not sufficient. To partially meet the plant's nitrogen needs, biological fixation of nitrogen is an alternative way. It is not expensive. It does not contribute to environment pollution. The work on agricultural microbiology with reference to Biological Nitrogen Fixation (BNF) is not only challenging but worthwhile for nations with small budgets for research.

Biological Nitrogen Fixation is a natural phenomenon in legume root nodules caused by *Rhizobium* bacteria helping grain legumes and fodder; in paddy fields where free-living blue-green algae and *Azolla* can be used with profit; in the root region of all plants where non-symbiotic bacteria are present, notably *Azotobacter chroococcum;* in forest ecosystems, e.g., Alder trees and *Casuarina* spp which have root nodules caused by *Frankia* spp; in graminaceous plants (e.g., sorghum, millets) where *Azospirillum* bacteria live in the cortical cells and xylem vessels helping in nitrogen fixation through "associative symbiosis."

What are the economics of biological methods compared to chemicals?

Response of plants to chemical fertilizers such as urea is dramatic, but the basic problem is that not all the chemical fertilizer applied is taken up by the plants. For instance, in the paddy ecosystem, 50 percent is lost by denitrification and runoff. In legumes, the application of chemical N fertilizers beyond 20 kg N/ha as starter doses is wasteful and in fact hinders biological fixation.

Biological fertilizers are inexpensive (Rs. 10 per hectare) and their effect is not as spectacular as urea but it does not contribute to environmental pollution and is slow and steady in effect. One kg of urea contains approximately 2.5 kg N and is available in India at a subsidised price of Rs. 2.75. On an average, biofertilizers would save about 30 kg N/ha which is equivalent to approximately 75 kg of urea costing around Rs. 200. Therefore, by the application of biofertilizers a farmer can save Rs. 200/ha by way of nitrogen. This saving is all the more important in crops where no fertilizer is generally applied as in the case of course millets.

Don't the prerequisites for infrastructure and delivery systems on the one hand, and the sensitivity of the biological agents to specific conditions of temperature, rainfall, etc. on the other, tend to outweigh the benefits in economic terms?

As a matter of fact, chemical fertilizers are more prone to denitrification and losses than biological fertilizers. The effectiveness of biological fertilizers is minimized by antibiotic producing soil microorganisms, predators, high soil temperature and drought. Some of these limiting factors are also operative in crops fertilized with mineral fertilizers because 75 percent of the crops in India are rain fed where limitations of water availability creates problems for fertilizer utilization. In fact biological fertilizers operate better under rainfed conditions because of the copious polysaccharides produced by nitrogen fixers which act as soil conditioners.

The delivery of biofertilizers at the farmers level is one of the toughest problems faced by the biofertilizer industry. The biological products are also vulnerable to environmental hazards. There is, therefore, a case to decentralize biofertilizer factories to meet the rural needs of people. It is here that one has to differentiate between chemical fertilizers and biofertilizers. That is, you cannot produce chemical fertilizers on a small-scale decentralized basis. In fodder sorghum, coarse millets, barley and fodder oats and leguminous crops such as bengal gram, cowpea, pigeon pea, etc. there is no organized or planned input of mineral fertilizers. Probably it is in these crops, under Indian conditions, that biofertilizers can play a vital role.

Can biological methods ever replace chemical altogether?

The answer is an emphatic "No." Biological methods can at best provide limited amounts (up to 30 kg N/ha) and can only work in conjunction with chemical fertilizers unless one finds super bacteria or super plants possessing artifically transplanted 'nif' genes.

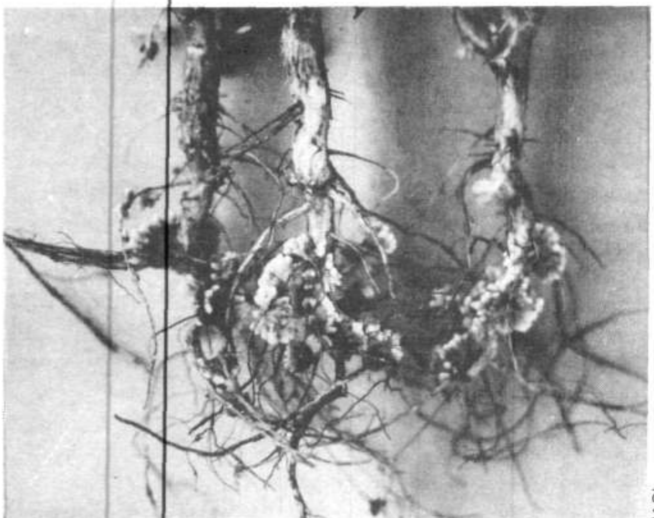
Are biological methods of enhancing plant growth simply a "low cost" way to achieve urgent but limited progress, or are they most efficient or otherwise optimal from a technical-scientific standpoint?

These low cost biological methods are not certainly, as matters stand at present, the most efficient way of harnessing nutrients to crop plants, but it has to be borne in mind that the continuous application of chemical fertilizers to soil damages the soil structure and the soil is rendered useless for the future generation. Probably, it is in this context that biological methods have an edge over chemical methods.

With regard to nitrogen-fixation, would it be more efficient, would the result be better to enhance this capability genetically, i.e., via gene manipulation and transfer? How close is this prospect to being realised?

Optimistically and theoretically speaking, the transfer of nif genes is certainly the best potential answer to meet the nitrogen nutrition of crop plants. We have a long way to go in this direction, and probably in the next two decades we may visualize a situation when plants thrive on their own without the need for fertilizers.

There are some approaches to achieve this end. At the present time, nitrogen fixing nodulated plants are confined to those species of leguminosea which bear nodules and to members of diverse families of the plant kingdom whose root nodules are inhabited by species of actinomycetes tentatively classified under the genus *Frankia*. These nodulated plants are nearly self sufficient with regard to their nitrogen nutrition and therefore a question has been posed whether it is possible to convert as many other land plants as possible into nitrogen fixers, more particularly cereals, so as to harness atmospheric nitrogen to a greater degree than has now been possible. In other words, can the nif genes from nitrogen fixing microorganisms be transferred to a higher plant? This involves the nuclear recombination between a prokaryote and a eukaryote which poses a host of problems including compatibility of genomes. Nevertheless, through molecular cloning techniques, certain possibilities or strategies have been outlined.



IARI

Nodulated roots.

Agrobacterium tumefaciens (Crown gall bacterium) is a common soil bacterium. It infects dicotyledonous plants and forms cancerous outgrowths (tumours). This bacterium harbours a large plasmid, Ti, which is responsible for the formation of the tumour. A segment of the Ti plasmid which carries the genetic information for tumour gets implanted in the host cell genome and thus gets replicated. Therefore, once initiated, the crown gall can go on indefinitely without the need for fresh *A. tumefaciens* infection. This is possible because the tumour inducing principle in Ti plasmid genes is transferred from a bacterium to a higher plant. Here is an instance of how nature has overcome genetic barriers between a lower plant (prokaryote) and a higher plant (eukaryote). It has been envisaged that nif genes could be'transferred to a Ti plasmid by molecular cloning, and the latter used as a vehicle to implant nif genes into higher plants.

Other possible vehicles for molecular cloning of nif genes are plant viruses like cauliflower mosaic virus DNA and chloroplast DNA. Of the two, the chloroplast approach is likely to offer least resistance. The strategy is to construct bacterial plasmids carrying nif genes and integrate them into chloroplasts. Later, the nif chloroplast plasmid is introduced into isolated chloroplasts. This is followed by the introduction of "transformed" chloroplasts into isolated plant protoplasts.

Uptake of nitrogen fixing bacteria and blue-green algae into higher plant protoplasts has been attempted as a possible method of modifying higher plants cells to fix nitrogen. In a similar way, cells and tissues of plants have been shown to take up nitrogen fixing bacteria. Regeneration of such calluses into intact plants capable of fixing nitrogen is a distinct possibility, although not seriously attempted up to the seedling stage in recent years. Recently cells of *Azotobacter vinelandii* have been forced into the mycelium of *Rhizopogon*, a mycorrhizal fungus on the roots of pine. If this approach is successful, then we can have nitrogen fixing mycorrhizal roots. Nif genes from *Klebsiella pneumoniae* have been cloned into yeast cells (*Saccharomyces cerevisiae*), but there has been expression of nitrogen fixation character in the recombined yeast.

Where do you foresee the next breakthroughs in your area, and in "biotechnology" most broadly?

From the agricultural point of view, biotechnology holds promise to the poorer nations as f llows:

1) creation of new bacteria and fungi by DNA recombination which can act as biopesticides. We have already with us *Bacillus thuringiensis* which acts against lepidopterous insects. We must transplant genes governing the production of biopesticides to other quickly growing bacteria on the same lines as *E. coli* mediated insulin production to fight diabetes. By growing reconstituted cells in large fermentors or bioreactors, we can make large quantities of biopesticides.

2) to cultivate plants or clones from reconstituted protoplasts which have incorporated genes for quick vegetative growth for fuel and fodder (e.g., *Leucaena*), i.e. quick biomass yielding plants.

3) by combining phosphate solubilizing and nitrogen fixation capacity in one organism, we can have plants independent of chemical N and P fertilizers.

4) by artifically growing mycorrhizal fungi, the root systems of many plants can be inoculated to form beneficial new root associations.

5) in the area of bioconversion, the direct conversion of lignocelluloses to power alcohol by a one-step enzymatic process. If this is done we can convert, for example, sugarcane juice as well as baggasse into alcohol. Even major unused biomass could be generated to yield alcohol.

6) generation of methane gas from agricultural wastes by "super microorganisms" through genetic engineering.

7) to generate plants resistant to pests and diseases.

What, in your view, are the implications of the rapidly developing "biotechnology revolution" for developing nations? How should they prepare themselves to adopt and use these technologies, and help push them further?

The implications of biotechnology cannot be understood clearly at the moment. Nevertheless, considering the spectacular achievements in the DNA recombinant technology, it is clear that we are on the verge of major breakthroughs in industry, medicine and agriculture.

Developing nations are eager to derive the benefits of biotechnology. The scientists and students have been excited by hopes of a bright future. Biotechnology needs expertise, material supplies, training, monetary input and, above all, constant touch with advanced nations where most of the current thinking on the subject is being generated. Abroad, biotechnology research is in the hands of private enterprise and experienced professors are being wooed into companies. The research results are being patented and may not be available easily for poor nations.

There is, therefore, in India a national biotechnology board which has been entrusted with the task of identification and implementation of national projects in biotechnology. The Council for Scientific and Industrial Research has already located a Microbiology Institute at Chandigarh and the Department of Science and Technology, the University Grants Commission and Indian Council for Agricultural Research have similar plans to upgrade teaching and research in DNA recombinant technology. Above all, a close link with internationally reputed industries is envisaged. We hope we are in the right direction.

Dr. N.S. Subba Rao is Head of the Division of Microbiology of the Indian Agricultural Research Institute, New Delhi, and Project Coordinator of the All-India Project on Biological Nitrogen Fixation, the first such organised effort in the world. Dr. Subba Rao has served as a Visiting Professor at the Institute Pasteur in Paris, Nagoya University in Japan and Macdonald College in Quebeq, and has been associated with FAO, UNDP and the International Institute of Tropical Agriculture. He is the author of several books and the editor of two reference volumes. For his contributions to soil microbiology, Dr. Subba Rao was awarded the P.B. Sarkar Endowment Prize by the Indian Council of Agricultural Research in 1981. He has been elected as a Fellow of the Indian National Science Academy. Most recently Dr. Subba Rao received the Borlaug Award for his outstanding contributions in the field of biological nitrogen fixation and bio-fertilizer technologies.

Revolutionising Medical Practice

An Interview with Dr. Pornchai Matangkasombut

What do you consider to have been the major recent contributions in biotechnology, and where do you think the next breakthroughs will be?

If you start from the traditional area of biotechnology that has been productive for decades and in some areas for hundreds of years, fermentation technology and more recently enzyme technology, they will all have the limitation of the slow process of strain selection and improvement by the traditional methods. The advent of gene splicing, recombinant DNA, and so on, really made the whole game different. You can design the organism as you wish. This has been made use of rather rapidly, with a very short lag time between the time you were able to cut genes and piece them back together the way you wanted, and produce new products such as interferon, insulin, and growth hormones.

But there are still limitations here. Even now it's much easier to put genes from one so-called prokaryotic cell into another one. But manipulating genes from eukaryotic cells—yeast, protozoa and many other cells—is still limited in as far as our ability to get them to express is concerned.

Another new technology, cell fusions, gave another big boost to this whole game; this is particularly useful in the case of yeast, plant cells and mammalian cells. We were able to make hybridomas of antibody-producing cells with myeloma so that they would be immortalised and grow to do one thing, make one single kind of antibody. This is an important tool too in analysis, in characterising relevant macromolecules, and also in diagnosis of diseases.

The next breakthrough will come exactly in this area of manipulation of mammalian cells, and it is not far away. We might be able to change genes right in our own cells. For those who have genetic defects, it might be possible to put those properties back into the person so that the defect is no longer there.

What does this breakthrough hinge upon? Is it a technical problem at this stage, or are there certain fundamental questions about our understanding of the process that have to be solved?

Both really, but there are areas in which we already know a great deal about the genetic basis of the defect, for example, in thyrocemia and other hemoglobinopathy. Interestingly, we know a great deal about genes that regulate the immune response. And of course the abnormality of immunoregulation contributes to a great variety of diseases. In most circumstances we still cannot pin down what specific defect in what specific genes or gene function produces a given disease entity, but we are not far from elucidating this for some diseases.

Once more of this is known, prediction will replace the horoscope of the palmist or astrologist. When a child is born, theoretically you can take a drop of his blood and run it through a number of tests involving various kinds of markers that etch out a loci, immunoglobulin allotypes, various enzyme polymorphisms, and so on. Then the computer can tell you, it it's programmed properly, what is the likelihood of his growing up and having this or that disease. An in fact we might come to a stage where we can say that he's most likely to get that illness *if* he encounters this or that other factor.

That would totally revolutionise medical practice. But what you're describing in terms of health and human beings is, I think, much more developed than the corollary for plants.

Yes. Medicine has a distinct advantage: people complain about their illness, and thus we have a good record of what can be wrong with people. There are tens of thousands of varieties of complaints and sets of syndromes, conditions and diseases, whereas you rarely know if the plant is not happy... only a few people can talk to them, let me put it that way.

But of course the potential contributions, the future contribution through genetic engineering is already here in the agricultural field. In animal husbandry, for example, even at the moment, without doing recombinant DNA, we can do a lot of tricks with *in vitro* fertilizations to expand a good breed, combine the proper pedigree to produce certain hybrids and expand that particular breed very quickly. Now, if you are able to add genes freely into the ovum or spermatozoa even at the blastocyst level in cattle or poultry, this is a different story.

To what extent is the swift forward motion in biotechnology forcing fundamental changes in our theory of the origins and nature of life?

Well, there are already some fundamental principles that have been shaken. For example, for a long time a basic dogma in biology regarding cell differentiation in multicellular organisms was that during differentiation you may have changes in expression and non-expression of a certain set of genes, but the basic genetic material is always conserved. Therefore you could take a somatic cell and take a nucleus and put it into the cytoplasm of an early zygote and you could grow up a whole new frog, for example, indicating that all the genes were there.

This is not true. Gene splicing, gene cutting and rejoining, is a *natural event.* In cutting and rejoining genes now we make use of naturally occurring enzymes. It's not Roy Gilbert or someone else who made these enzymes. They simply discovered a natural process in which genes are being cut, and intervened into it to make use of it. The best known example now is how the structural genes for immunoglobulin are organised.

Immunoglobulin, as you know, are the molecules that make up antibodies, that *are* antibodies. In fact the genes for the light chain, for example, of immunoglobulin do not exist in a single structural gene for the whole chain. Rather it's made up of at least three different parts, and organised into a big stretch of chromosome. The part that accounts for antibody specificity, the so-called variable part, is represented by a number of copies, such that depending on what copy you join with the other part, you have a different amino acid sequence and therefore different specificity. In the process of the lymphocyte differentiating into making antibodies, these genes are being relocated and parts in between are cut off so that the proper variable portion genes join with the adjoining portion and the constant part.

So a cutting and throwing away is a regular event, but the part that is being thrown away happened to be not so much if you consider the totality of the genetic material, so we were not able to detect it before. Now we know that it's being thrown away like mad, and a well differentiated plasma cell is making a single kind of antibody. In fact, it may have thrown away *all* of the other genes for making other kinds of antibodies.

So the question is what triggers or motivates those activities...

What regulates this? Part of the answer is already known. Because we know that for frequent differentiation of B lymphocytes into making antibodies, for example, you require interaction by other cells, so-called helper T lymphocytes, to give a message to the B lymphocytes: "Hey, this is something that you should think about, making antibodies..." The symptomology we know. In fact, we know the structure and part of the sequence, and we also know what gene this signal molecule comes from. The immune system happens to be a model that attracted a lot of interest from the beginning. It happened to be a model with characteristics that make the analysis of how cells talk to one another an important aspect. Therefore we keep on trying to find out how the cells talk to one another, what is the molecular basis of this language, and what genes determine who can say what to whom.

This alone can lead to a lot of future breakthroughs. When people talk about hybridomas, they are thinking of B cell hybridoma, monoclonal antibodies. But in the last two years the T cell hybridoma, the cell that regulates the immune response are now available. So you can have hybrid clones of these different cells such that each of them has a specific message to give—and these are now being characterised—and it might be possible to put them on the shelf. There could be a shelf of suppressor T cell messages for various kinds of antigens, so if the lady is allergic to ragweed, then we pull out one tube containing

We are trying to find out how the cells talk to one another, what is the molecular basis of this language, and what genes determine who can say what to whom.

suppressor cell for ragweed IgE production, and that's the end of that.

So regulatory genes in mammalian cells will be the next breakthrough, and the first, I would guess, would be regulatory genes for immune response, because we already know quite a bit about it. And we already have the tool, the T cell hybridoma. This is a lot of fun.

Very recently a new government decision was taken in Thailand to promote a concentrated programme in biotechnology.

Yes. This can be considered to be the first of the major financial inputs into a given area of science, and it could also be considered to be the prototype of other goal-oriented approaches in defined areas.

For biotechnology, it's very simple. It's not difficult for the government—politicians, technocrats, economists—to recognise that a country like Thailand that is rich in biomass, producing an abundant amount of foodstuff and other agricultural products, would be particularly benefitted by biotechnology, which is really whatever technology that can use biological processes of microorganisms to convert things around according to what we need. If you consider that our export of agricultural raw materials each year amounts to several billions of US dollars; and if we were to export a little bit less of that and convert it into value-added products, to replace importation of similar products, or even to export the finished products rather than the cassava pellet, for example, we might increase the value of such exports to 1000-fold. The impact on the whole economy is no small matter. From that standpoint, investing US$ 15-20 million into this particular area is not that much money, really.

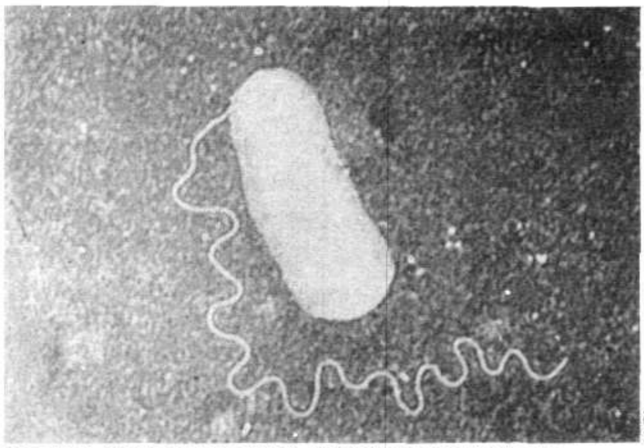
More important, it's the first time that a substantial amount of money is being put into one key area, one target area.

Could you describe the current work going on in biotechnology in Thailand?

The work in biotechnology is very wide-ranging. A number of institutions have keen interest, and have ongoing programmes. The work can be divided into three groupings: one with potential industrial applications, one with an agriculture-oriented approach and application, and then applications in health and sciences.

As far as industrial application is concerned, much of the work for medium and large-scale industry is still quite preliminary. In fact, most of the medium-scale and large-scale industries import their technologies en bloc, turnkey processes. In small scale industry, on the other hand, the number of things that have been done and put into actual applications, including new processes and new microbial strains, is significant. For home industry—like soy sauce factories that traditionally in Thailand are carried on in cottage-type of industrial settings, and with mixed cultures or undefined cultures—for example, our scientists now are able to characterise the key properties of certain cultures, improve on them and devise a pure culture, such that the impact of these for the cottage industry is very significant. In fact, as a result many of them grew into a mechanised level of industry and are now expanding.

For larger-scale industries, there are a few examples of innovative work. Our scientists at Kasetsart University, a university that was originally an agricultural university, in collaboration with a Japanese colleague, have been able to use protoplast fusion techniques and to select hybrids of fusion strains that combine the properties of high-yield alcohol and also flocculant.


IARI

Electron photomicrograph of Rhizobium *bacteria.*

As far as agriculture is concerned, a great deal of work has been done on plant strain selection, breeding and so on, including tissue culture and protoplast fusion techniques in several areas. Rice, of course, is one of our main crops and a great deal of work has been put into that. Orchids of course should be mentioned. And various tropical fruits have been improved by using traditional as well as modern methodology, like *in vitro* culture and fusions.

Then another area in which we have grown rather intensively and extensively has to do with nitrogen fixation, using *Rhizobium*. The Agriculture Department is already producing one hundred tons of *Rhizobium* for distribution to legume-growing farmers. This is just simply for seed inoculation, and then from field testing they improve the yield considerably.

In nitrogen fixation, work is being done on microorganisms that may live symbiotically with rice and that can fix nitrogen. This will be quite important. As far as phosphorous is concerned, mycorrhiza is being worked on, but it is still quite preliminary.

Of course there is a great deal of work done on *Candida* and other organisms, using waste from pineapple, canning factories and what not to produce industrial proteins. There is a great deal of potential to use these as animal feed.

Another area of industrial application is compost fertilizers. As you know, we are net importers of a great deal of chemical fertilizers. We will be in a position to produce our own chemical fertilizers in the next few years, once the petrochemical industry becomes developed, which it must because we have to process our own crude and our own natural gas anyway. In the meanwhile, the government has been importing quite a bit of inoculant for compost fertilizer, and disseminating them as well as the technique to the farmers. But these strains were derived from mostly temperate zone countries. They were tested here and found to be effective, but that doesn't say that we could not find better local strains. So, a great deal of work is being done on screening and strain selection from the local scene.

Another area for agricultural application is pest control, which is also related to vectors for disease.

How did this broad research capability come into being in Thailand?

In the days of absolute monarchy, in the days of King Rama IV, who was a very enlightened monarch, a very learned person, we started to send students to study in top institutions in Europe, including science. That was 100 years ago. These people came back and started to establish, at the beginning, small schools and graduate departments in universities. King Rama V expanded that scheme considerably. He happened to have 200-some children, and all of his children were sent abroad to study various fields. Usually each of the princes was accompanied by a so-called king's scholar, a commoner who was qualified to go on for further studies. These people came back around the turn of the century, and established various branches of modern services and institutions, including medical sciences, agricultural sciences and basic natural sciences.

Of course, even now we still have students going abroad for studies, particularly in those areas where we do not have our own graduate programmes. And we are fortunate in that most of our people come back and stay. We have had very little brain drain.

The most recent part of this 100-year process you describe was in the 1960s I take it, when, at least in terms of Mahidol, there was quite a concentrated development of the basic sciences.

Throughout the 100 years that I mention, the people who went into basic science, the theoretical aspects particularly, became rather frustrated because they were not so many and critical mass was not built. Many of them remained rather inactive. On the other hand, the more applied aspects of science and technology, agriculture, industrial engineering, or other areas of engineering, medical sciences, particularly clinical sciences, were very attractive to younger people. So we had a problem of people going into this area more than into basic sciences.

The Faculty of Science of Mahidol University was created only 25 years ago. The first dean, Professor Stang Mongkolsuk, was a very far-sighted person, and he recognised this problem. So he devised a scheme to "siphon off" the top students from the pre-medical school class, who happened to be the top students of the country, to go into basic sciences by offering them scholarships to go to Harvard, or Oxford, or Cambridge, or Berkeley, Wisconsin—wherever they wanted to go. He was able to recruit more than 100 top students from the pre-medical school class and put them into physics, chemistry, biology and life sciences.

This resulted in an infusion of higher-calibre young people into basic, fundamental research. This is a critical point in that the strength of life sciences gathered critical mass within at least some institutions, and with other institutions. In the last 15-20 years this has been strengthened, and the critical mass—once you get it in certain key areas and they begin to grow, then the momentum is there—was extended into more areas of competence.

The next phase is really to organise this into more systematic kind of task forces, which would be able to perform goal-oriented research and development. Many people in developing countries keep on arguing, particularly among those so-called science policy experts, that why should developing countries do basic science; we must have "appropriate technology"; and so on and so forth. To me this argument is all a bunch of nonsense. There is no work that you can say, "This is basic, that is applied," and "This is appropriate and that's not." If you look at the whole thing from the point of view of goal-orientation, then you have to consider what we have so far and what is needed. In most areas you cannot help but go back to the most fundamental and build from it. You may say, "Oh, this is too fundamental"—but if you want to reach that goal, you have to have it.

Dr. Pornchai Matangkasombut is Chairman of the Department of Microbiology, a position he has held since 1973, and Director of the Biotechnology Programme in the Faculty of Science at Mahidol University in Bangkok, Thailand. The Faculty of Science is the principle centre in Thailand for training medical students in basic science at the undergraduate level as well as the most important centre in research and graduate training in the life sciences.

Dr. Pornchai was Chairman of the National Organizing Committee for the Fifth International Conference on Global Impacts of Applied Microbiology, held in Bangkok in 1977 under UN sponsorship. Dr. Pornchai is part of the team that formulated Thailand's bid to host the proposed new UNIDO-sponsored International Centre for Genetic Engineering and Biotechnology.

A medical doctor and Ph.D. in Immunology, Dr. Pornchai is an Editor of the Asian Pacific Journal of Allergy and Immunology *launched by the Allergy and Immunology Society of Thailand in June 1983.*

Genetic Engineering Vs. Pollution

A Status Report by Dr. A.M. Chakrabarty

The application of a large number of synthetic chemicals, particularly the highly chlorinated aromatics, in the form of herbicides, pesticides, industrial solvents, dielectric fluids, etc. has created major problems of environmental pollution all over the world[1]....The major reason for the pollution problem is the persistence of these chemicals, i.e., they remain unchanged in the environment for a long time, and because most of them are lipophilic, they tend to enter into the human body through the food chain and remain stored in the fatty tissues where they exert their toxic effects. It is clear that insecticides and herbicides such as DDT, 2,4,5-T, etc., whose production and usage have been curtailed in the U.S. as well as some other countries, could have been used for enhanced agricultural productivity or eradication of insect-borne diseases, if only such compounds could be rendered harmless through microbiological degradation.

Plasmids in Biodegradation

Although most highly chlorinated compounds are degraded only slowly in nature by cooxidative process[2] and others are not degraded at all, many bacteria are known to degrade simple chlorinated (mono or dichlorinated) compounds rapidly as a sole source of carbon and energy. In some cases the genes for the dissimilation of these compounds have been shown to be borne on plasmids. Interaction of the plasmids appears to be a potent mechanism for the evolution of new capabilities against other, similar types of compounds. For example, following the demonstration of Hartmann *et at*[3] that inclusion of TOL in a chemostatic culture is essential for conferring the ability in a 3-chlorobenzoate degrading pseudomonad to utilize 4-chlorobenzoate or 3,5-dichlorobenzoate, we have demonstrated that under such conditions, a part of the TOL plasmid is not only transposed onto the chromosome to supply a needed broad substrate benzoate oxygenase function, but that the plasmid TOL also supplies the replication functions for the evolution of a new plasmid that harbors mutationally altered gene segments from the chlorobenzoate plasmid so as to allow efficient degradation of a dichlorobenzoate such as 3,5-dichlorobenzoate[4].

Since chlorocatechols are common intermediates in the degradation of chlorinated aromatics compounds, transfer of plasmid-borne genes encoding degradation of chlorocatechols to cells capable of utilizing phenol, salicylate or aniline (but incapable of utilizing chlorinated derivatives of these compounds), has allowed the development of microorganisms capable of utilizing chlorophenol, chlorosalicylate[5] or mono- or dichloroaniline. Another interesting feature of genetic selection is the extended substrate range against other halogenated compounds....

In addition, different plasmids are known to contribute different segments of a degradative pathway, so that more than one plasmid might be necessary for the degradation of a synthetic chlorinated compound[6]....

There are other compounds that are found widely in toxic waste dump sites (2,4,5-T, 2,4,5-trichlorophenol, pentachlorophenol, etc.) that are quite recalcitrant to microbial attack when present at high concentrations.... Since new degradative functions have been shown to evolve through divergence of chromosomal or plasmid-borne genes, it was of interest to see if bacterial strains, capable of utilizing a compound such as 2,4,5-T, could be developed by chemostatic selection in presence of a pool of plasmid genes. Indeed, such selection allowed the emergence of a pure culture of *Pseudomonas cepacia* AC1100 that could utilize 2,4,5-T as its sole source of carbon and energy[7,8], while an identical control selection medium without plasmid gene pools did not produce any 2,4,5-T degrading strain. The strain *P. cepacia* AC1100 could not only utilize 2,4,5-T, but could also dechlorinate a variety of other chlorinated compounds such as 2,4-D, pentachlorophenol, 2,4,5-trichlorophenol, various mono-, di-, tri- and tetrachlorophenols, and so forth[9,10]....

AC1100 in an Open Environment

One of the major unanswered questions in the application of genetically-engineered microorganisms in an open environment for pollution cleanup is whether such microorganisms would be effective in utilizing the specific pollutants under conditions where they have not only to compete with indigenous microorganisms for mineral and other nutrients, but would also have ample other carbon sources present as alternate foods. We have demonstrated that AC1100 is not only very effective in removing more than 95 percent of 2,4,5-T at moderate concentration (1000 ppm) from the contaminated soil in about a week[11], but that it can remove more than 90 percent of the 2,4,5-T when it is present at very high concentration (20,000 ppm) in about 6 weeks[12]. Removal of the 2,4,5-T allows the soil to support the growth of broad-leaf plants which are normally very sensitive to low concentrations (10 to 50 ppm) of 2,4,5-T.

This indicates that microbial removal of 2,4,5-T from heavily contaminated soil allows a total restoration of the original soil condition. Once the 2,4,5-T is gone, the titer of AC1100 drops rapidly and the bacteria become undetectable in a few weeks[12]. This further indicates that in absence of 2,4,5-T, laboratory-developed strains such as AC1100 cannot compete effectively with indigenous microorganisms and tend to die off rapidly. Such microorganisms are therefore unlikely to cause any major ecological disturbances, if they are applied in contaminated areas in large amounts.

In Conclusion

It appears that genetic techniques could be very useful in developing in the laboratory new strains capable of degrading novel synthetic compounds. We have recently demonstrated that the entire 3-chlorobenzoate degradative genes can be cloned in a broad host range vector and transferred to various gram negative bacteria[13]. Although promoter sequences controlling transcription of *Pseudomonas* plasmid-borne degradative genes appear to be different from those of *E. coli*, and therefore such genes often remain unexpressed in enteric and other bacteria[14], molecular cloning of chromosomal or plasmid-borne degradative genes as part of broad host range plasmid vectors will undoubtedly facilitate gene transfer among the microbial community....

We have recently developed a mixed culture that can utilize dibenzothiophene, a major source of sulfur in various high sulfur coal and crude oil, as its sole source of carbon and sulfur. Undoubtedly, many other bacterial strains can and will be developed, each capable of utilizing rapidly one or more recalcitrant compounds. It would be interesting to see if, similar to the 2,4,5-T degrading strain, such cultures will also be able to utilize the xenobiotic compounds in contaminated soil and remove the pollutants permanently from the environment.

Dr. A.M. Chakrabarty is Professor of Microbiology at the University of Illinois at Chicago. Chakrabarty has done pioneering work in the application of genetic engineering techniques to problems of environmental pollution. The above was excerpted from a presentation Dr. Chakrabarty made to the United Nations Environmental Programme in Paris in July, 1983.

REFERENCES

1. Schneider, M.J., (1979). Persistent Poisons: Chemical Pollutants in the Environment. The New York Academy of Sciences, N.Y.
2. Alexander, M., (1981). Science *211*: 132-138.
3. Hartmann, J., W. Reineke and H. -J. Knackmuss, (1979). Appl. Environ. Microbiol. *37*: 421-428.
4. Chatterjee, D.K. and A.M. Chakrabarty, (1982). Mol. Gen. Genet. *188*: 279-285.
5. Reineke, W., S.W. Wessels, M.A. Rubio, J. Latorre, U. Schwein, E. Schmidt, M. Schlomann and H. -J. Knackmuss, (1982). FEMS Microbiol. Lett. *14*: 291-294.
6. Furukawa, K. and A.M. Chakrabarty, (1982). Appl. Environ. Microbiol. *44*: 619-626.
7. Kellogg, S.T., D.K. Chatterjee and A.M. Chakrabarty, (1981). Science *214*: 1133-1135.
8. Kilbane, J.J., D.K. Chatterjee, J.S. Karns, S.T. Kellogg and A.M. Chakrabarty, (1982). Appl. Environ. Microbiol. *44*: 72-78.
9. Karns, J.S., S. Duttagupta and A.M. Chakrabarty, (1983). Appl. Environ. Microbiol. (in press).
10. Karns, J.S., J.J. Kilbane, S. Duttagupta and A.M. Chakrabarty, (1983). Appl. Environ. Microbiol. (in press).
11. Chatterjee, D.K., J.J. Kilbane and A.M. Chakrabarty, (1982). Appl. Environ. Microbiol. *44*: 514-516.
12. Kilbane, J.J., D.K. Chatterjee and A.M. Chakrabarty, (1983). Appl. Environ. Microbiol. *45*: 1697-1700.
13. Chatterjee, D.K. and Chakrabarty, A.M., (1983). Gene (submitted).
14. Chakrabarty, A.M. D.A. Friello and L.H. Bopp, (1978). Proc. Natl. Acad. Sci. U.S.A. *75*: 3109-3112.

New Los Alamos Breakthroughs Point to Compact, High Density Magnetic Fusion

by Charles B. Stevens

Los Alamos National Laboratory scientists have achieved a series of experimental breakthroughs with their compact toroid and reversed field types of magnetic fusion systems, including the zeta pinch. Taken together with similar types of magnetic fusion research going on in plasma laboratories throughout the world and, in particular, in Japan, these results constitute the most significant advance yet achieved in fusion technology and science.

The experiments indicate that magnetic fusion devices such as the spheromak can become self-sustaining at high densities, thus making possible an ideal fusion reactor that burns advanced fusion fuels efficiently at an extremely low capital cost.The impact of the Los Alamos breakthroughs are threefold:

First, the Los Alamos developments have immediate theoretical and practical implications for all the various approaches to harnessing magnetic fusion energy, for the development of directed energy (laser, particle, plasma, and hypervelocity projectile) beams, and for the technology of pulsed power, which is essential to both fusion and directed energy systems.

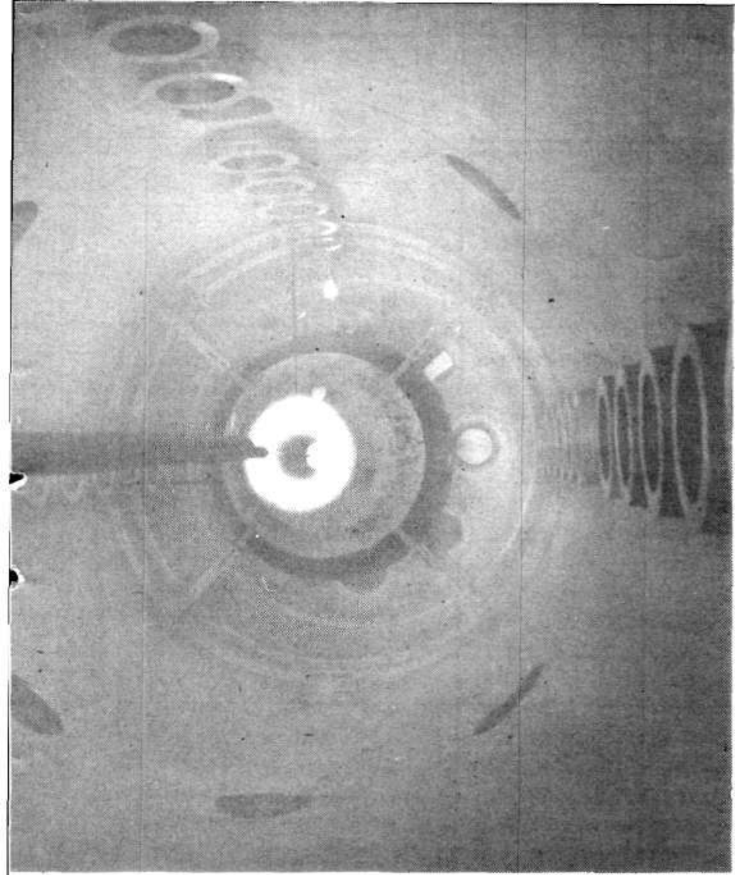
Second, the Los Alamos experiments demonstrate how an almost ideal magnetic fusion energy system can be achieved. This ideal system would be based on self-organized magnetic plasmas that are capable of continuously and efficiently generating fusion energy outputs with a minimum external supporting technology. In other words, this system would be a fusion reactor with a minimum capital cost. Such a fusion system would generate electricity and other forms of industrially needed energy at costs far below those of existing technologies and below those projected for the existing mainline fusion approaches now being researched.

Third, and most significant, these fusion experiments are transversing the frontiers of science as defined by Riemannian relativistic physics. For example, the Los Alamos results have immediate theoretical implications for electrodynamics and the definition and evolution of self-organized structures such as solitons and shock waves. This advance opens up an extremely fruitful path for the experimental reformulation of quantum electrodynamics as recently specified by Lyndon H. LaRouche.[1] The recent theoretical applications of self-ordered soliton-type plasma structures to biology demonstrate that the potential impact of these Los Alamos results is not limited to physical science.[2]

Fusion and Plasma Science

From an economic standpoint fusion cannot be defined as just another potential energy resource, and plasma physics is not just the science upon which the technology for harnessing fusion is based. The fusion process provides the basis for defining and developing entirely new families of resources. For example, fusion transforms simple water and earth and existing forms of industrial waste into valuable resources. And plasma physics, particularly as demonstrated in the fusion torch concept, defines an entirely new industrial technology that has a potential of infinitely higher efficiencies and densities of throughput compared to existing types and has no moving parts.[3]

This economic potential of fusion, defining the parameters for a new industrial revolution, is foreshadowed by the role of nuclear fusion and plasma processes in the evolution of the universe. Fusion is the source for the most active forms of energy observed in dynamics of the universe. It is nuclear fusion energy that makes the stars shine, and it was


Los Alamos National Laboratory

Inside view of the vacuum chamber of the Los Alamos National Laboratory CTX fusion experiment in which the spheromak is formed.

the fusion process that generated the spectrum of chemical elements (matter), out of which the solar system was formed.

The easiest elements to fuse are the heavy isotopes of hydrogen, deuterium (D), whose nucleus has one proton and one neutron, and tritium (T), whose nucleus has one proton and two neutrons. It has been experimentally determined that when the average energy of the electrons and heavy hydrogen (with equal quantities of deuterium and tritium) is the same, the conditions for net-energy-producing thermonuclear fusion can be stated as an ignition temperature (temperature is a measure of the average energy, and therefore the velocity, of an ensemble) and a specific density of reacting nuclei that must be maintained over a specific period of time. For D-T fusion, the minimum ignition temperature is 44 million degrees Celsius or 4,000 electron volts (1 electron volt is equivalent to about 11,000 degrees Celsius or 1.6×10^{-19} joules). And the density in nuclei per cubic centimeter times the time during which this temperature and density are maintained must be equal to 30 trillion seconds-nuclei per cubic centimeter. This energy confinement time/density product is termed the *Lawson condition* for net fusion energy generation.

There are two general approaches to thermonuclear fusion: inertial confinement and magnetic confinement fusion.

In inertial confinement, extremely high power densities are applied to an ensemble of deuterium-tritium fuel, and the fuel burns up before it blows up. That is, only the inertia of the fuel is utilized to confine it to a specific density while it is heated to fusion ignition temperatures.

Magnetic fields are generated by electric currents—a directed relative motion of electrons and ions. For magnetic confinement fusion, these fields can be generated by either external electric circuits such as sets of copper coil magnets or by electrical currents induced within the confined plasma itself. In general terms, the applied magnetic field, whether from an internal or external source, acts as a countervailing force to the gas pressure of expansion exerted by a hot plasma.

From electrodynamics it has been shown that magnetic field lines must form closed circuits. Two important features of plasma magnetic confinement follow from this observation: (1) internally generated magnetic fields will be utilized more efficiently than externally generated ones, and (2) the ideal geometry for magnetic confinement is that of a torus formed out of closed magnetic field lines.

The mainline magnetic fusion approach, the tokamak, is indeed a torus, which derives a significant portion of its confining magnetic field from a toroidally directed plasma electric current. In the tokamak, most of the confining magnetic field is generated by external copper field coils. As noted above, however, the ideal situation would be to obtain the entire confining magnetic field from internal plasma currents. And, indeed, this is the primary characteristic of the Los Alamos compact tori: the CTX spheromak and the FRX-C reversed field theta pinch. Both these devices form closed tori of magnetically confined plasma in which the confining magnetic fields are generated by closed loops of plasma electric current.

The geometry of these magnetic confinement devices is shown in Figure 1. In 1 a, a column of plasma is trapped in an axial magnetic field, where the field lines follow the axis of the cylinder. When this axial magnetic field is generated by a plasma current, this configuration is called a theta pinch. The plasma electrical current flows in an azimuthal direction, circling around the plasma column as shown. The name theta refers to the angular coordinate of this circular path.

In 1 b, the geometry of the magnetic field and plasma electric current have been reversed. The field lines are circular—that is, in the theta direction—while the plasma electric current flows along the axial direction, which is generally given the coordinate designation of zeta. This configuration is termed a zeta pinch.

The reason for the name pinch is that these magnetic confinement configurations are dynamic. The inward pressure exerted by the magnetic field is greater than the plasma gas pressure of expansion. As a result, the column is "pinched" to a smaller radius. Since this by definition increases the plasma current density in both the theta and zeta pinches, the magnetic field intensity increases and therefore the inward magnetic pressure increases.

Both pinches can be made into closed tori (1c) simply by taking the ends of the columns and connecting them. In this case, the axial or zeta direction becomes the toroidal direction—the long way around the torus, while the azimuthal or theta direction becomes the poloidal direction—

the short way around the torus. The Los Alamos FRX-C is a closed toroidal theta pinch, while the CTX spheromak is more like a toroidal belt pinch, where the magnetic field and electric current follow the same spiral paths. The Los Alamos reversed field ZT-40 zeta pinch is a much more complex system, which is described below.

The rate at which fusion reactions take place increases with the fuel density, and therefore the power density of the fusion energy output also increases with the fuel density. However, since the plasma gas pressure increases with increasing density, the confining magnetic fields must be made more intense.

This brings us to the most crucial observations concerning magnetic plasma structures. Matter that is held together by ordinary chemical bonds, such as copper wire, is limited to the energy flux densities—magnetic and electric fields—that it can withstand given the strength of these chemical bonds, which are less than a few electron volts per atom. Self-organized magnetic plasmas—that is, plasmas in which the primary confining magnetic fields are generated by internal plasma electric currents—have no energy flux density limitations. Therefore, self-organized magnetic plasmas offer a unique path to both the most efficient and highest energy flux density fusion plasma configurations.

Theoretical Origins of Self-Organized Magnetic Plasmas

In January 1980, in an article titled "The Zeta Moves into First Place," *Fusion* made a projection for the experimental

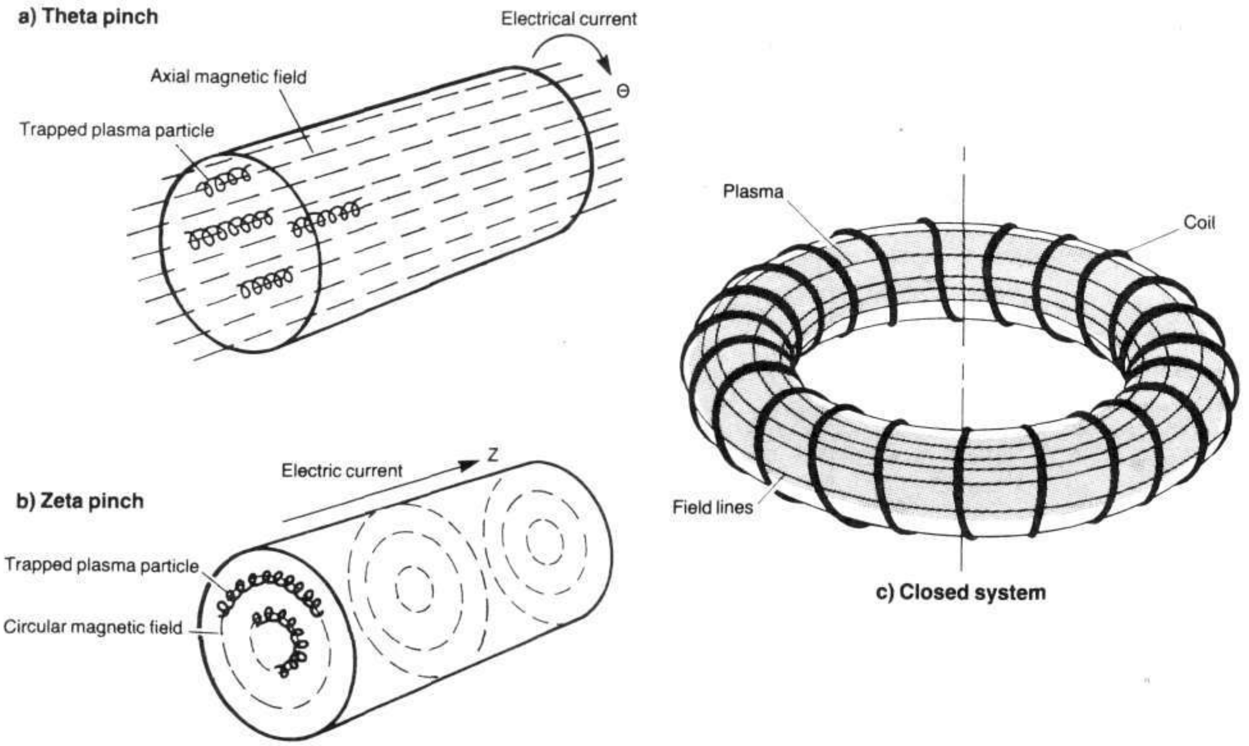


Figure 1
MAGNETIC CONFINEMENT CONFIGURATIONS

The configuration for a theta pinch is shown in a. *An axial magnetic field traps plasma ions and electrons into spiral orbits along the field lines. A plasma current is induced to flow in a circular fashion, the short way around the cylinder, known as the theta direction. This generates a magnetic field parallel to the axis of the plasma cylinder. If the induced plasma current is made to increase rapidly, then the intensity of the magnetic field will increase. This compresses and heats the plasma, which, in turn, leads to an intensification of the magnetic field. This process of a plasma current generating self-compression is called the plasma pinch.*

The configuration for a zeta or z-pinch is shown in b. *A circular magnetic field—the poloidal field—traps plasma particles in "closed" spiral paths along "closed" magnetic field lines. The induced plasma current flows in a direction parallel to the central axis of the plasma—the long way down the cylinder, termed the zeta direction.*

A combination of the theta and zeta pinch configurations will generate spiral-shaped magnetic field lines and electrical current paths.

The magnetic field configuration shown in c *has been closed by bringing the ends of the cylinder together to form a toroidal shape—a donut. The field lines now are closed. Also shown is an external coil that generates the magnetic field within the plasma.*

development of self-organized magnetic fusion systems.[4] The recent Los Alamos successes confirm the projections made in that article as well as the essential aspects of the earlier work of Drs. Harold Grad of the New York University Courant Institute for Mathematical Studies, Dan Wells of the University of Miami at Coral Gables, and Winston Bostick of the Stevens Institute of Technology and the Kirtland Air Force Weapons Laboratory.

To briefly summarize this history: During the 1930s, Dr. Adolf Busemann applied the concept of Riemannian shock waves to aerodynamics and derived the essential features of isentropic flow, which made the development of rocket and jet aircraft possible.[5] He also applied this concept to fusion and derived the fundamental features of inertial confinement. Later, while working for NASA in the 1950s, Busemann developed the essential features of self-organized magnetic plasmas.[6]

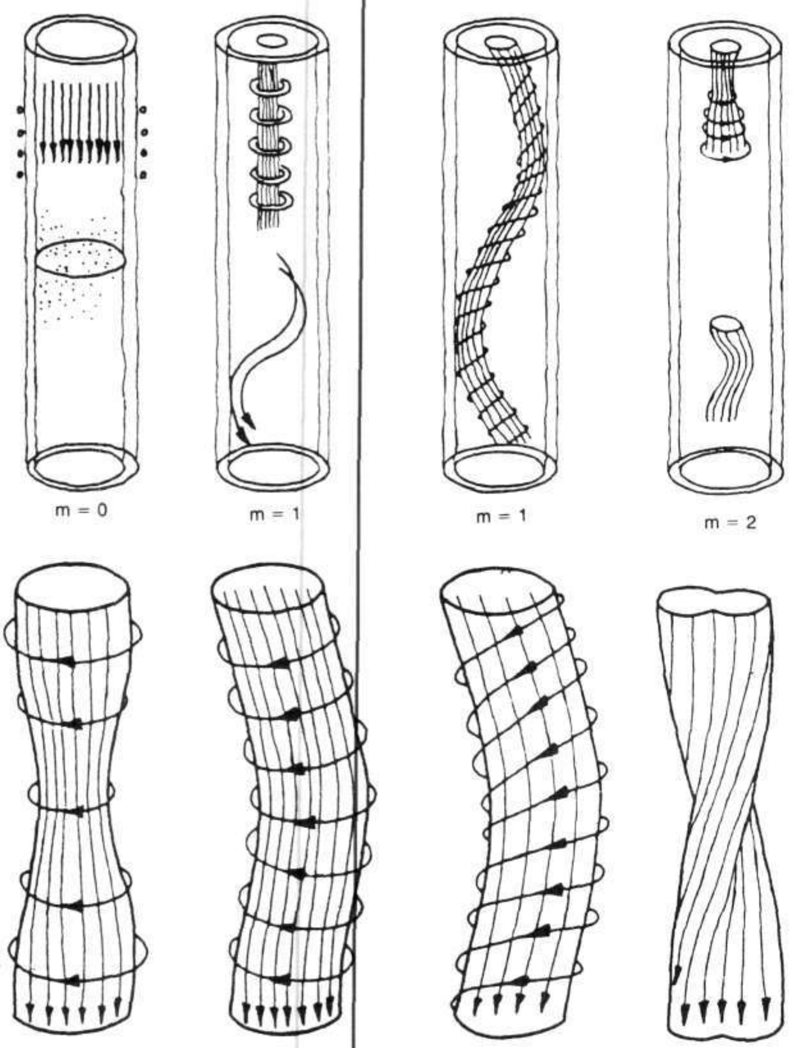
The essential point is that the evolution of magnetic plasmas is dominated by continuum hydrodynamical processes and their singularities—vortices. The plasma domain is represented by a higher-ordered hydrodynamical continuum, which is called magnetohydrodynamics or MHD. In this domain, magnetic fields represent a sort of higher-order fluid superimposed and strongly interacting with the plasma fluid (see Figure 2). These MHD vortices exist in two *distinct families, and Dr. Fred Tappert of the University of* Miami at Coral Gables has shown that given a magnetic plasma, such MHD vortices will naturally appear. Furthermore, Dr. Harold Grad has shown that given the proper global boundary conditions, these MHD structures will evolve to more complex topologies—defined by growing numbers of field geometry singularities—without dissipation.[7]

In the 1960s, Dan Wells applied the experimental obser-

Figure 2
MAGNETOHYDRODYNAMIC (MHD) PLASMA INSTABILITIES

A plasma column in a magnetic field can become hydrodynamically unstable as a result of the interactions between the plasma, which is moving like a fluid, and the confining magnetic field. These motions, or MHD instabilities, as they are termed, evolve according to specific harmonic geometries. The set of diagrams here shows how these harmonic motions can be characterized.

In the terms used to identify the various instabilities, m *is an integer in a mathematical function of the form sin* (mΘ) *that determines the geometry of the MHD motion. For example,* m = 0 *means that the plasma column will move only in a radial direction (that is, with differing thicknesses). In* m = 1, *the plasma column motion takes the form of a spiral or simple coil—a kink—and if this continues to grow, the plasma will hit the wall of the vacuum chamber. In* m = 2, *the column spirals and is squeezed at the same time.*



vations of Winston Bostick and extended the theoretical insights of Busemann to the dynamics of these self-organized structures.[8] Wells showed that these MHD structures represented metastable minimum energy states.

An important point here is that if the global boundary conditions of the system—the placement of the vacuum chamber wall in which the magnetic plasma is being formed, the geometry of the externally induced plasma electric currents, and so on—are not properly chosen, the evolution of these MHD structures will appear as instabilities leading to the destruction of the magnetic plasma. For example, as shown in Figure 2, MHD motions can cause the plasma to come in contact with the vacuum chamber wall. As a result, the plasma would rapidly lose its thermal energy to this wall and recombine to form an ordinary, un-ionized gas that has no free electrons.

However, if the boundary conditions provide sufficient freedom for the plasma to progress to a new, higher-ordered minimum energy state, then this apparent MHD instability will dissipate once such a higher state is achieved. In 1974, J.B. Taylor of the Culham Fusion Laboratory in England utilized Dan Wells's concepts (without acknowledging him, in fact) to demonstrate that this is precisely what happened in the case of the British toroidal pinch experiment called the Zeta.[9]

The Zeta experiment was basically a toroidal zeta pinch, as shown in Figure 3, with some toroidal axial magnetic field added in order to stabilize the z-pinch against the $m = 0$ MHD mode in Figure 2. Originally, it appeared that the system became completely unstable. Closer examination of the experimental data after the Zeta was shut down, however, showed that the system entered a phase of dynamic MHD motions but then settled down into a quiescent stable phase. To the surprise of the fusion researchers involved, this quiescent phase had an entirely new magnetic geometry that had been created during the dynamic phase.

What apparently happened in the Zeta is that an $m = 1$ MHD mode developed and moved around the plasma column. In the process, it disrupted the toroidal magnetic field lying outside the plasma column and then reconnected the magnetic field such that the field was now directed in an opposite direction. That is, the toroidal magnetic field outside the plasma column was reversed with respect to the direction of the toroidal magnetic field originally imposed on the plasma and the toroidal field remaining within the plasma column. This phenomenon was termed self-reversal, and the Los Alamos ZT-40 is based on this reversed field configuration.

The essential point to conclude from this example of the Zeta device is that if self-organized magnetic plasmas are given sufficient freedom in terms of their boundary conditions, they will "naturally" proceed in a dynamic fashion to higher-ordered configurations. It is the exploration of these boundary conditions, correlated with the dynamic evolution of these higher-ordered structures, that defines the most crucial characteristics and limits of magnetic confinement in general.

The unprecedented success of the Los Alamos ZT-40, and in particular the emergence of the dynamo effect, which is also now being observed in the CTX-spheromak, categorically demonstrates that this is the case.

A final general point is that both the plasma and its boundary conditions are dynamic and experimentally exhibit distinct harmonic—resonant—structures in terms of their interconnection.

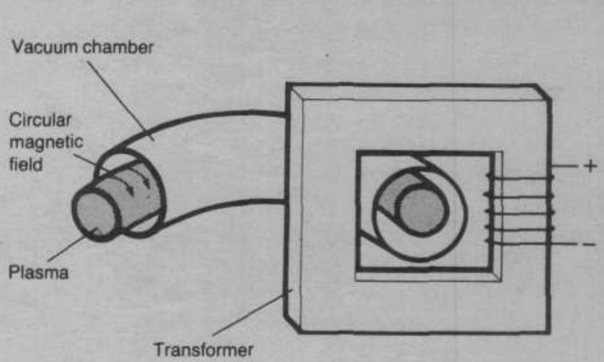


Figure 3

CUTAWAY VIEW OF A SIMPLE TOROIDAL Z-PINCH

In experimental runs, hydrogen gas is pumped into the vacuum chamber to fill up the donut at a low density. Then an electric current is passed through the transformer. This generates an electrical current field that ionizes the hydrogen gas in the vacuum chamber. As the current rises in the transformer, a plasma electrical current is induced to travel around the donut. This generates the circular (poloidal) magnetic field that pinches and initially heats the plasma. As the current continues to rise, it too heats the plasma.

In the later, more sophisticated versions of the toroidal z-pinch, toroidal field coils were placed around the vacuum chamber. These generated an axial (toroidal) magnetic field that helped to stabilize the simple z-pinch against MHD instabilities. Also, "vertical" field coils were added that prevented the plasma donut from simply expanding and hitting the vacuum wall. The vertical field coils generate a magnetic field on the outside of the plasma donut in a direction perpendicular to the plasma column. When the plasma expands outward, it interacts with this vertical field and is forced inward as a result.

The CTX Spheromak

The spheromak configuration is an almost ideal projection of the fundamental concepts that Wells first initiated. In the spheromak, all the confining magnetic field is generated by plasma currents, creating an axisymmetric toroidal pinch configuration.

The Los Alamos CTX spheromak is shown in Figure 4, and Figure 5 shows how the CTX spheromak is dynamically generated with a coaxial plasma source called a Marshall gun (only the plasma gun is shown for simplicity). The plasma gun consists of two cylindrical electrodes that are contained in a vacuum chamber. A low density hydrogen gas fill is introduced into the chamber and a large voltage drop

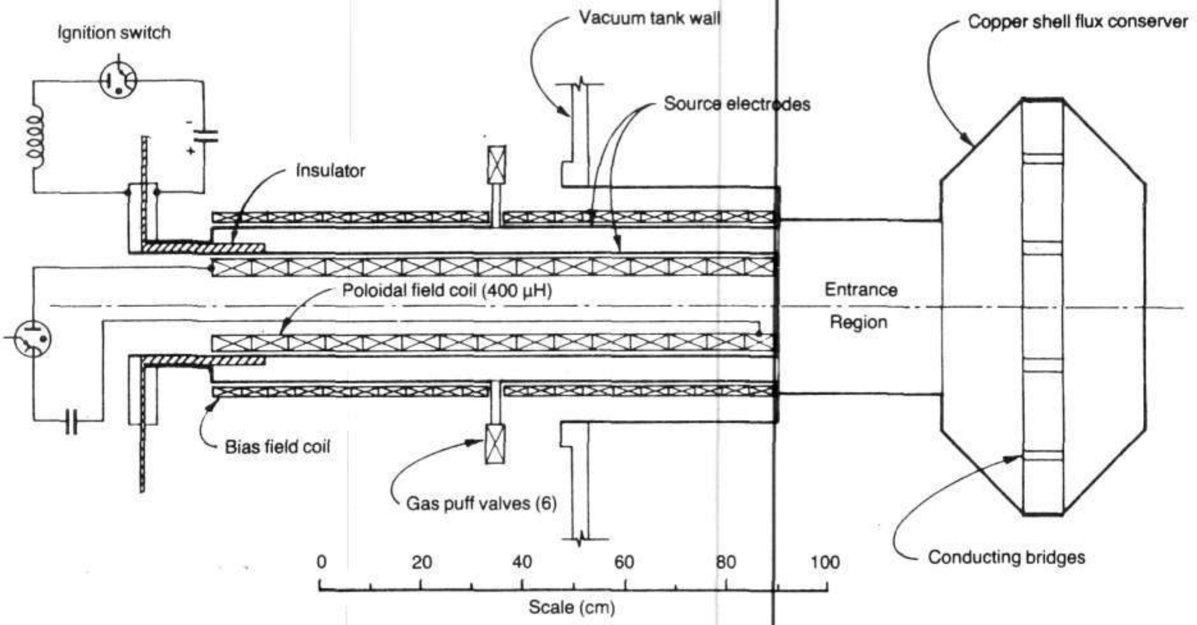


Figure 4
CROSS-SECTIONAL SCHEMATIC VIEW OF THE CTX SPHEROMAK

The diagram shows the Los Alamos CTX spheromak experiment and its electrical circuit. The gas puff valves provide an intake of hydrogen gas. Then the two cyindrical source electrodes, which form the coaxial Marshall gun, are switched on. This then generates a plasma sheath on the left side of the Marshall gun near the insulators. The plasma sheath moves to the right down the gun. When it emerges from the left end of the coaxial gun, the plasma sheath is transformed into a spheromak and interacts with the poloidal magnetic field generated by the poloidal field coil. The completely formed spheromak continues to move to the right until it is trapped within the copper shell flux conserver.

is applied to the two electrodes. The resulting electric field between the electrodes causes the hydrogen gas to break down (ionize) near the left side of the electrode cylinders. Once a plasma sheath is formed between the electrodes, electrical current begins to flow through it from one electrode to the other. The flow of current along the surface of the electrodes—in the axial direction—generates a toroidal magnetic field.

The current flowing through the plasma sheath interacts with this toroidal field to generate a force that propels the plasma sheath toward the right side of the cylinder. When the sheath reaches the end of the coaxial gun, it encounters radial magnetic flux generated within the inner cylinder of the gun. Because of the momentum of the plasma sheath, the interaction between the plasma sheath and this radial flux generates a snipping effect that causes the radial lines to reconnect around the plasma sheath as it emerges from the gun. As a result, the flat sheath is rolled up into a torus with both toroidal and poloidal magnetic field components. This process is shown schematically in Figure 5.

The plasma continues on its trajectory toward the right until it enters a flux-conserving cage made out of copper. The copper cage serves as an external boundary force, which is needed to maintain stability even though force-free self-organized plasma structures are primarily confined by their own magnetic fields. This external force is marginal, however, compared to the forces exerted by the internal magnetic fields.

If the plasma begins to move—for example begins to tilt—electrical currents are induced in the copper cage by the moving magnetic fields in the plasma. This current generates a magnetic field that acts on the CTX torus in a direction opposite to its motion. This effect is used both to halt the plasma motion to the right and to stabilize the configuration.

Spheromak experiments are being carried out in fusion labs throughout the United States and Japan. Although other spheromaks have been dynamically generated with alternative startup systems, the CTX is the first spheromak to burn through the impurity radiation barrier.

During the startup phase of magnetic fusion experiments, plasma energy flows are dominated by atomic radiation generated by heavy element impurities. All magnetic plasma systems begin operation with significant quantities of nonhydrogen elements in them. The source of these impurities derives from the metal electrodes, the vacuum chamber walls, and the vacuum system itself. Because of the higher energy electron orbit structure associated with these heavy elements, in a plasma these nonhydrogen impurities will radiate energy out of the plasma at a very rapid

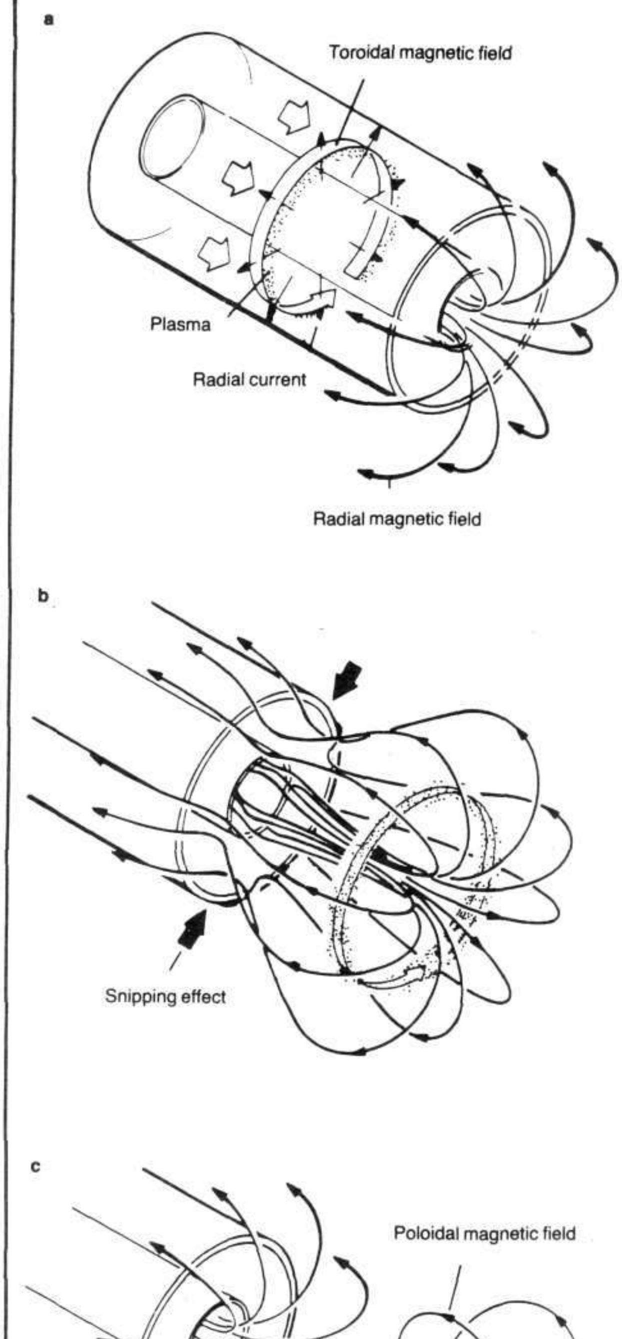


Figure 5
MAGNETIC FIELD GEOMETRIES IN THE STARTUP OF THE CTX SPHEROMAK

These three diagrams show how the CTX spheromak is formed. In the first stage, a, *the coaxial Marshall gun (represented by the two cylinders) generates a plasma sheath that carries a large, radially directed electrical current between the two cylindrical electrodes of the Marshall gun. At the same time, the current flowing along the cylindrical electrodes generates a toroidally directed magnetic field.*

*The interaction between this toroidal magnetic field and the radial plasma current results in a force on the plasma directed toward the right, down the cylinder. The plasma, therefore, accelerates down and out of the coaxial gun (*b*). Because of the momentum of the plasma sheath, the interaction between the plasma sheath and the radial flux creates a snipping effect that causes the radial lines to reconnect around the sheath as it emerges from the gun.*

*At this point, the flat plasma sheath is rolled up and becomes a plasma ring or torus. This ring then interacts with the radial magnetic field generated by the poloidal field coils within the inner cylindrical electrode (shown in Figure 4). This interaction leads to the formation of a self-contained spheromak configuration (*c*) whose magnetic field consists of both poloidal and toroidal components. The completely formed spheromak continues to move to the right until it is trapped inside the flux conserver (shown in Figure 4).*

rate. If the magnetic plasma can be maintained for a sufficient period of time, these impurities will generally diffuse out of the plasma in a process termed "burning through the impurity radiation barrier."

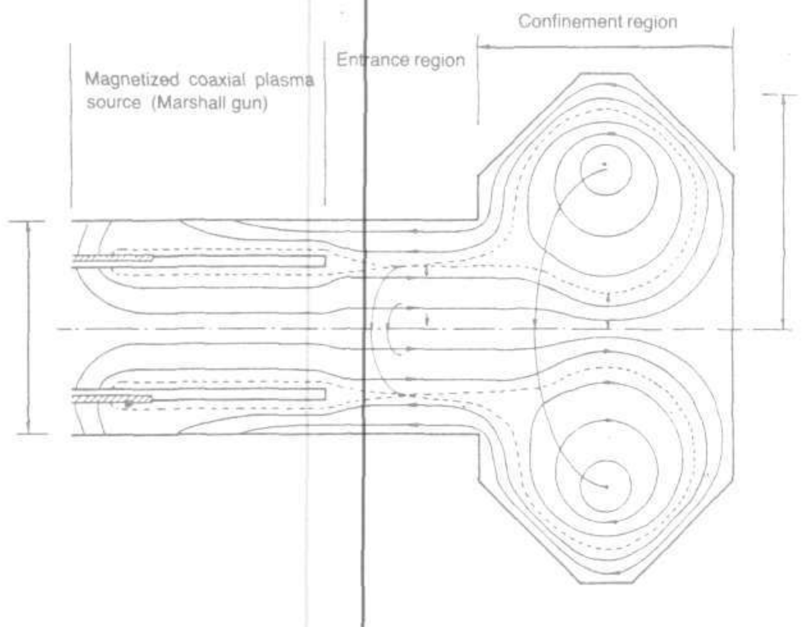
The CTX achieved success in overcoming this impurity stage by implementing cleanup routines that removed most of the impurity sources before the CTX operation and then by using a *porous* copper flux conserving cage instead of the solid one that had been used previously. The porous nature of the copper wire cage apparently enhances the migration of impurities out of the CTX plasma region, and the geometry of the wire permits the development of plasma sheaths around the copper, which, in turn, prevent the migration of impurities from the copper wire itself.

The key observation demonstrating that the impurity radiation barrier has been superseded is that the CTX plasma begins to heat up because of the electric currents flowing in it. This form of plasma heating is called ohmic heating. Peak electron temperatures of several hundred electron volts have been measured.

When Los Alamos initiated its compact tori and zeta pinch reversed field programs in the mid-1970s, it was believed that extremely high power pulsed electric systems would be crucial. This proved not to be the case with the ZT-40, and it is again being shown to not be true in the case of the

Figure 6
SCHEMATIC OF
STEADY-STATE SPHEROMAK

The diagram shows a cross-section of the CTX spheromak and its magnetic field components. The lines in the plane of the schematic represent poloidal magnetic field lines. The circular lines coming out of the diagram represent the toroidal magnetic field lines. The closed spheromak structure contains both toroidal and poloidal magnetic fields. If the coaxial gun is kept on it will directly regenerate the toroidal field within the closed CTX. However, the spheromak structure itself acts on incident toroidal field to transform a part of it into poloidal field within the CTX.



CTX. The original CTX experiments utilized a fast generation mode with input powers of 10 to 15 gigawatts. Now much better results are being obtained with much longer plasma sustainment times at power inputs of 100 to 800 megawatts.

In the fast mode, spheromaks were formed within 3 to 6 microseconds. In a slower startup mode, with 200 to 800 megawatt electrical current power levels, formation of the CTX took about 60 microseconds. Both the slow and fast modes decay in the same manner over 950 microseconds.

The Dynamo Effect

Los Alamos researchers have seen indications of a third experimental mode for the CTX. If the coaxial gun is left on at a low power level, it appears that the formed CTX spheromak is absorbing the magnetic flux and plasma coming out of the gun, and some of this incident toroidal flux is transformed into poloidal flux within the CTX spheromak (Figure 6). This opens up the prospect of a steady-state spheromak. The key point here is that while toroidal flux within the spheromak can be directly regenerated by the gun, only the apparent action of the plasma dynamo can provide a source for the essential poloidal flux.

Although the question of how and why the ZT-40 and CTX plasma dynamo action develops is for the most part still unanswered, it appears that this self-organized phenomenon is closely related to the Wells concept mentioned above of metastable minimum energy states. One crucial aspect of the Wells theory is that magnetic plasmas will tend to form into force-free vortex configurations. Taylor showed that this tendency is probably the cause for the dynamic progression of the toroidal z-pinch to a reversed field configuration. The trajectory toward this more stable state can be shown in a *F*-theta diagram (Figure 7), where *F* and theta are ratio measures of the geometry of the magnetic field structure: *F* is the ratio of the toroidal magnetic field mea-

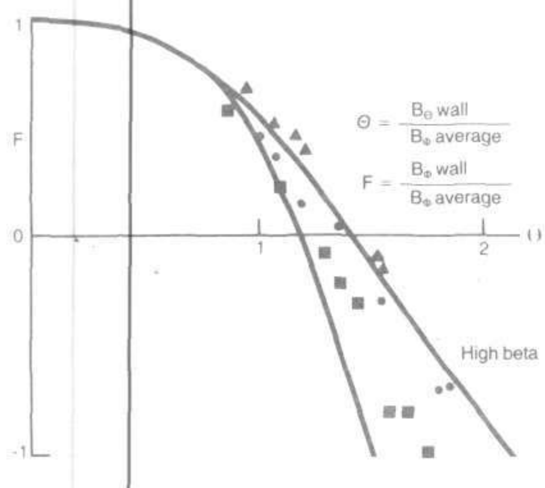


Figure 7
GEOMETRIC RELATIONS OF
MAGNETIC FIELD STRENGTHS IN
MAGNETIC CONFINEMENT

The graph shows the geometric relations of the magnetic field strengths for magnetic confinement. F, the y axis, is the ratio of the toroidal magnetic field found near the wall of the vacuum chamber, B_Φ, to the average toroidal magnetic field found throughout the plasma. Theta here is the ratio of the poloidal field B_Θ found at the wall to the average toroidal field throughout the plasma.

Tokamaks are located in the upper left region of the graph, while the reversed field pinches are the points plotted within the shaded area.

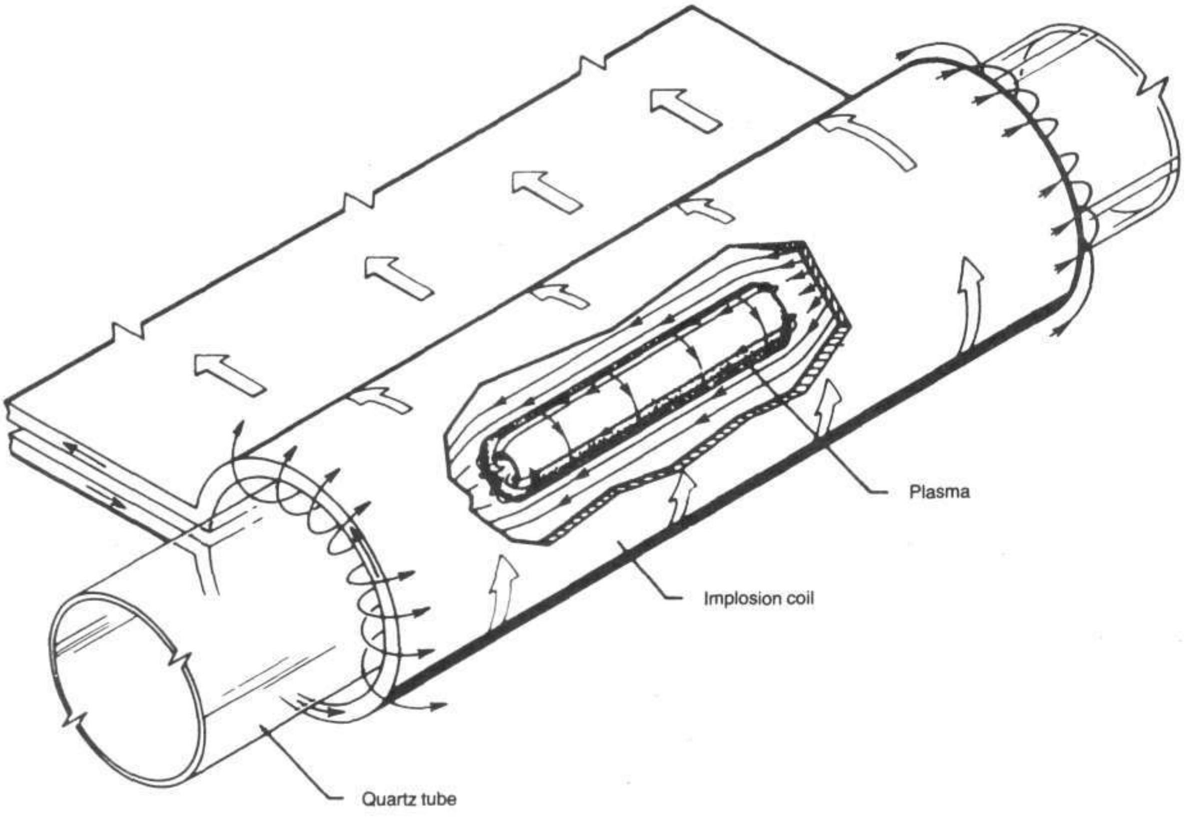


Figure 8
SCHEMATIC OF THE FRX-C REVERSED FIELD THETA PINCH
In this general configuration of the fully formed FRX-C reversed field theta pinch, the arrows show the direction of the magnetic fields generated by the electrical current in the implosion coil and the FRX plasma ring. The general plasma background is separated from the coil by a quartz tube vacuum chamber.

sured at the vacuum chamber wall to the average toroidal magnetic field throughout the plasma column. Theta is the ratio of the poloidal magnetic field at the wall to the average toroidal magnetic field throughout the plasma column.

The fundamental criterion of minimum energy states demands that all self-organized magnetic plasma structures conserve their force-free vortical (or helical) geometry. Also it requires that the dynamic evolution of these minimum energy states follows a specified trajectory in the phase space defined by the *F*-theta diagram since these parameters are a direct measure of the force-free nature of the geometric structure of the combined magnetic fields. The most straightforward explanation for this is that the plasma is generating this dynamo in order to maintain its minimum energy geometry.[10]

In fact, ongoing experiments indicate that the CTX could be sustained by a steady-state gun at power levels sufficiently low to use existing electrical technology. Dr. Thomas Jarboe projected such steady-state spheromak operation based on both the ZT-40 experimental results and the theoretical prediction that the spheromak minimum energy configuration will act to conserve magnetic helicity—that is, act as a dynamo to maintain the magnetic field geometry.[11]

The densities achieved in the CTX are several hundred trillion nuclei per cubic centimeter, comparable to those found in tokamaks but at much higher plasma betas. Once these initial results have been corroborated and the plasma dynamo sustainment mechanism definitively demonstrated, plasma heating experiments must be carried out to demonstrate that the CTX can be stably brought to the 100 million degree temperatures required for fusion.

If funds are available, heating experiments are planned within the next year or two at Los Alamos. The first heating method being planned is that of Alfven wave heating, where microwave generators are utilized to initiate Alfven waves external to the CTX. These Alfven waves form between the plasma and the magnetic field, and once within the CTX spheromak they would rapidly be damped and their energy would be transformed into thermal motion of the plasma electrons and ions.

The FRX-C Reversed Field Theta Pinch

While at first glance the FRX-C appears to be of an entirely different species from the CTX and ZT-40, its development has depended on the same general MHD theoretical developments that are exhibited in the CTX and ZT-40. At the same time, the FRX-C is sufficiently different from the CTX and ZT-40 to offer unique insights into that general theory.

The FRX-C is a reversed field toroidal theta pinch formed in a open-ended linear theta pinch system (Figure 9). This is accomplished by programing the currents in the theta pinch coil, as shown in Figure 10. As a result, the theta pinch plasma bunches up into the center of the cylinder defined by the coil. In this process, magnetic field lines are broken and reconnected to form an elongated, closed torus of poloidal magnetic field and plasma. This field is sustained by the toroidal plasma current induced by the external theta pinch coil.

The FRX-C is unstable to the m = 1 MHD mode. However, aware of the nature of this instability, researchers added additional magnetic field coils to the experiment to counteract the instability. As a result, stable operation has been achieved. Experiments indicate that energy confinement times between 70 to 190 microseconds are being reached at densities of several thousand trillion nuclei per cubic centimeter and temperatures of several hundred electron volts.

These results are extremely significant since the density-confinement time products attained on the FRX-C are comparable to those achieved on the early tokamaks, except that the FRX-C is operating at high plasma betas. The experiments also indicate that the energy confinement time scales as theory predicts. That is, the energy confinement time is a linear function of the radius squared of the overall torus, divided by the ion gyroradius. The ion gyroradius is proportional to the ratio of the square root of the ion temperature to the strength of the magnetic field. Furthermore, there are indications that better energy confinement time scaling can be attained by moving the plasma torus closer to the external field coil. From a practical standpoint, this would be best achieved by moving the FRX-C plasma torus into a new chamber in which a special coil system—not as complex as the startup coil—could be utilized to achieve this closer fit.

Construction of such a experiment is currently under way at Los Alamos.

Near Term Implications

The most dramatic immediate practical implications of these Los Alamos advances are in the areas defined by pulsed power technology and directed energy beam generation. According to the projections by Drs. J.H. Hammer and C.W. Hartman of Lawrence Livermore National Laboratory, the CTX has already entered the regime of interest for plasmoid acceleration.[12]

To be more specific, self-organized magnetic plasmas are inherently quite mobile. Once formed, they need only a minimal boundary force to keep them stable. This can be supplied by the pressure of the Earth's atmosphere or a simple flux conserving cage, as in the CTX case. (Without an external boundary force the force-free structure will rapidly disinegrate.)

Compact tori are also intrinsically easy to accelerate to high velocities because the ratio of the plasma ring's mag-

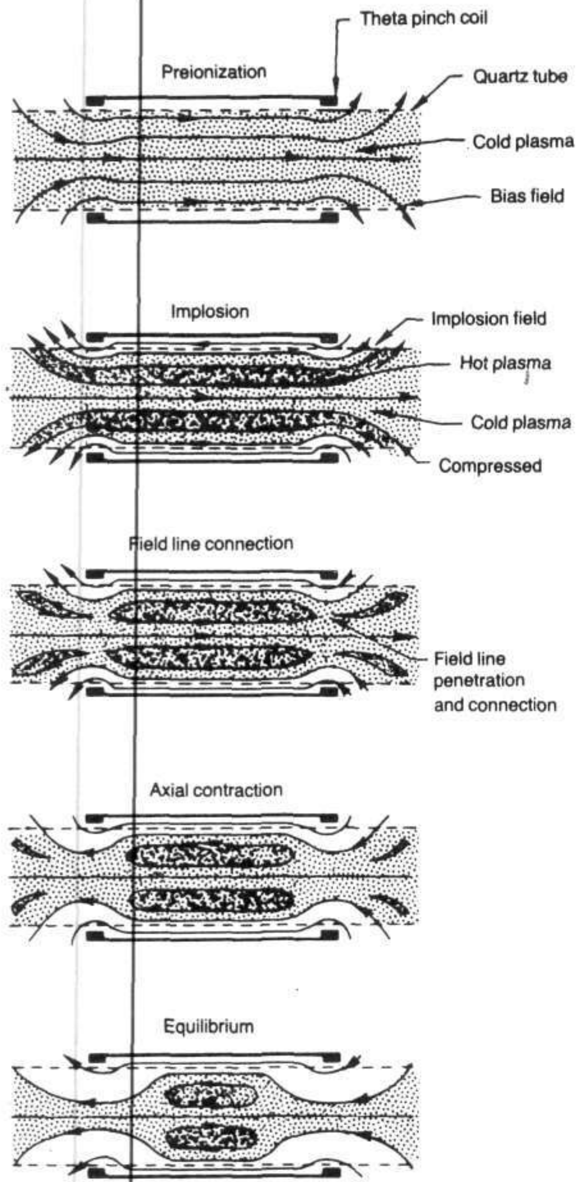


Figure 9
STARTUP OF THE FRX-C
REVERSED FIELD THETA PINCH

In the first of the five stages shown here, a cold plasma is formed by the current in the theta pinch coil. This magnetic plasma constitutes an open ended, simple theta pinch: The plasma is free to simply diffuse out the two ends of the theta pinch cylinder. (See Figure 8.) By rapidly increasing the current in the theta pinch coil the plasma column is imploded. And by programming this implosion current, the compression of the plasma is made asymmetrical. The result is that axial magnetic field lines are broken and reconnect to form a closed ring of magnetic plasma—the FRX-C.

netic field energy to its plasma mass is quite large, and potential acceleration of an magnetic dipole, such as a compact toroid, is a direct function of this ratio. It is the interaction between the magnetic field and an external electromagnetic force that can be utilized to accelerate the compact toroid.

In a 1980 Livermore Laboratory report, Dr. Hartman shows that substantial ring velocities and kinetic energies (the energy represented by the ring's motion) can be achieved in a magnetic rail gun, similar to that which generates the spheromak and of a quite reasonable length—several meters. This is particularly true in the case where the ring plasma is made up of heavy nuclei.

In a more recent series of papers given at the Fifth Symposium on the Physics and Technology of Compact Toroids, Dr. Hartman and his collaborators propose a two phase acceleration of plasma rings.[13] First, the ring is accelerated toward the apex of a conical magnetic rail gun. As a result, the ring undergoes a self-similar compression (focusing) during acceleration. And because the allowable acceleration force on the plasma ring is inversely proportional to the square of its linear size, the accelerating distance for conical electrodes is considerably shortened over that required for cylindrical coaxial electrodes. Furthermore, Hartman et al. note that in either case, "since the accelerating flux can expand as the ring moves, most of the accelerating field energy can be converted into kinetic energy of the ring leading to high efficiency."

During the second phase, the compressed plasma ring is accelerated again in a conical-shaped rail gun, but this time the plasma ring is allowed to expand. As a result, some of the energy contained in the magnetic field is converted into kinetic energy—that is, motion of the ring. In their calculation, the plasma ring attains velocities of 9,300 kilometers per second with about 50 percent of the input energy to the rail guns being transformed into the kinetic motion of the ring. It is quite probable that the atmosphere would provide the essential boundary force to keep the ring together during the time it traveled several hundred kilometers. Hartman et al. note: "If the ring at the maximum kinetic energy (4.4 MJ) were allowed to strike a target, the deposition power would be roughly 1.2×10^{16} watts (deposition time of about .3 nanoseconds) with a power density of 5.3×10^{15} watts/sq. cm." This would kill almost any target.

Hartman et al. note a range of other applications of accelerated plasma rings going from those where the input energy is comparable to the magnetic energy of the ring, to those where the input energy is larger than the magnetic energy, and, finally, to where the input energy is substantially larger. For example, at low energies accelerated plasma rings can be used for plasma current drive and plasma fueling.

At medium energies, accelerated rings can be focused radially by conducting cones that cause an increase in the field intensity and adiabatic heating. If the rings are designed to reach fusion temperatures, they can provide a high flux pulsed neutron source for simulating fusion reactor conditions and simulating nuclear weapons effects. Along these same lines, utilizing heavier elements in the plasma ring will cause the compressed rings to become copious generators of X-rays. By varying the elemental composition and plasma parameters of the ring, the spectrums of the X-ray radiation can be made to range over a myriad specified values. This is particularly useful in regard to pumping X-ray lasers and simulating nuclear weapons X-ray radiation effects. Another medium energy application is the development of high field moving ring reactors. At high energies, Hartman et al. point out, accelerated rings would have applications for fast switching/power amplification, as well as an inertial confinement fusion driver. As Hartman et al. describe, rings moving at about 1,000 kilometers per second with dimensions of less than 1 centimeter and kinetic energies of about 10 megajoules would match the power requirements for inertial fusion. In addi-

Los Alamos National Laboratory

Looking down on the Los Alamos ZT-40 reversed field toroidal z-pinch device. Technicians are shown making adjustments to the scientific diagnostics used on the ZT-40 experiments.

tion to the efficiency, the compactness of the accelerator (lengths of about 10 meters), they point out, is an advantage that makes this a reasonable candidate for fusion powered rocket propulsion.

Still another application is the synthesis of transuranic elements and the use of accelerated rings as a high flux ion source. Finally, two additional applications are noted, the attainment of super high magnetic fields and inertial fusion by sudden ring deceleration.

A second line of fusion application not mentioned by Hartman is that of utilizing the spheromak as the input for metal liner compression systems. A compressed spheromak is almost the ideal magnetic plasma input for such liner systems. The liner is quite similar in effect to the conical compression scheme outlined by Hartman, except that the metal electrodes consist of a cylindrical metal liner that is either explosively or electromagnetically collapsed. This causes a "stationary" compression of the spheromak plasma.

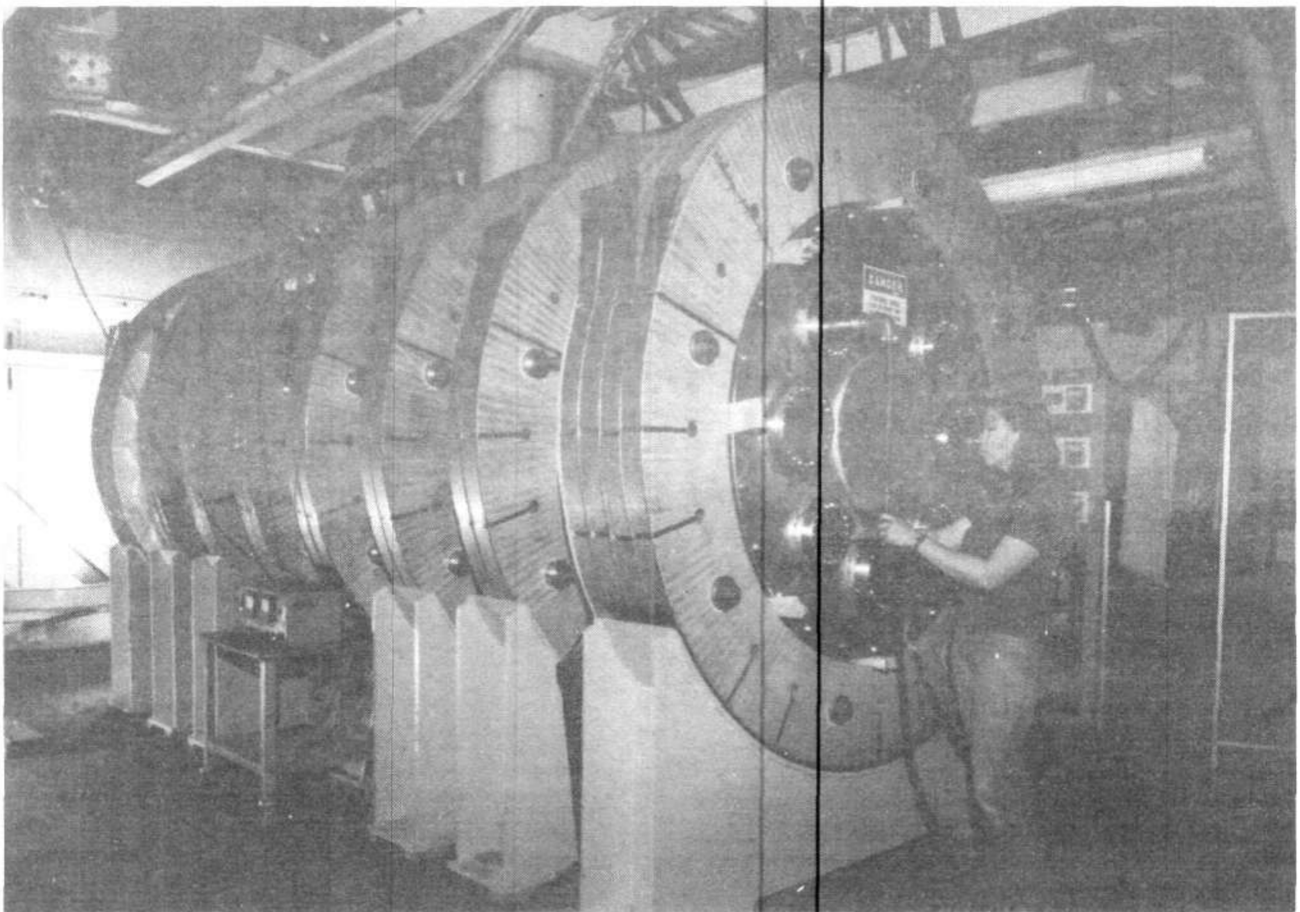
Magnetic Fusion Reactors

Because of the flat budget levels of the U.S. fusion research program maintained throughout the Carter administration and continued by the Reagan administration, research on alternatives to the mainline tokamak and tandem mirror magnetic confinement systems has been starved for funds. Hopefully, this situation will be changed in the near future, particularly given the directed energy implications of the developments described below.

From a theoretical and technological standpoint, there appear to be no significant barriers to the rapid development of the spheromak as a fusion energy system. All existing magnetic fusion experimental and theoretical knowledge strongly indicates that the spheromak should become more stable as it is heated to higher temperatures.

The CTX spheromak opens up the prospects for the development of an almost ideal magnetic fusion energy system that consists of several stages. In the first stage, the spheromak would be generated. The plasma ring would then be moved to another location and heated to fusion ignition temperatures. It would then be moved to a third location containing a simple, low power coaxial coil gun and flux conserving chamber needed for maintaining and fueling the spheromak. Fusion energy would provide the spheromak with an internal heat source sufficient to sustain fusion temperatures.

More so than any other type of magnetic confinement system, compact tori do not appear to be limited to the



Los Alamos National Laboratory

Vacuum chamber tank in which the Los Alamos CTX spheromak is formed. The tank is surrounded by external magnetic field coils. Originally it was thought that external magnetic fields would have to be used to stabilize the self-organized CTX magnetic bottle. However, experiments have demonstrated that external magnetic fields are not needed.

ultimate, stable operating temperatures that they can attain. This makes possible the burning of advanced fusion fuels—elements heavier than hydrogen. With these advanced fuels, significantly fewer neutrons are generated as fusion reaction products, thus lessening one of the chief engineering problems in fusion reactor systems: neutron-induced materials damage, a primary source for power density limitations in fusion reactors.

Developments along these lines are particularly bright if spin polarized fusion is successfully demonstrated and shown to be practical in the spheromak.[14] A neutron-free fusion plasma is particularly amenable to various MHD and direct particle methods of converting plasma energy into electricity. On the speculative side, directed fusion product effects, which derive from spin polarized fusion, could be combined with self-organized plasma effects to give the spheromak system a wide variety of energy output capabilities ranging from X-ray laser beam to microwave, through to electric and charged particle beam generation.

The economic prospects of compact tori fusion electric reactor systems can be judged by the above ideal possibilities, which are by no means necessarily remote at this time. The capital cost of such a system would basically consist of the cost for the flux conserving chamber, the low power gun, a control system, the vacuum chamber and pump, and an MHD coil or a direct particle conversion system. In the more versatile advanced case noted above, the plasma would directly generate the desired energy output. Furthermore, the gun could be replaced by a second spheromak. If located in space, of course, there would be no need for a vacuum chamber and pump. (The initiating system is an extremely small portion of the cost for an individual spheromak since it would be capable of generating thousands of such fusion plasmas per second.)

At this point in the description of such a system, it can be seen that the projected capital costs are being reduced to basically the control system and fuel. But since only extremely weak boundary forces are needed to control an individual spheromak, this means that the capital costs have been reduced to operating costs. In the case of fusion reactors in general, the operating costs, which include fueling, have already been shown in reactor designs based on more conventional type power plant designs to be only a small fraction of those found for all other types of power plants.

The result is the increasing prospect of perfecting fusion energy systems that have infinitesimal capital costs compared to existing types of systems. If viewed from the standpoint of energy payback time—that is, the time it takes the fusion reactor to generate the equivalent energy utilized in its construction—the energy payback time decreases from the several years of operation needed in the case of nuclear fission and more conventional fusion reactor designs to a few milliseconds in the case of the spheromak.

Viewed from the standpoint of versatile energy generation systems, these spheromaks could provide a universal modular unit for all industrial processes—both materials processing and forming. And as Hartman notes, the spheromak could be utilized as the most efficient form of rocket propulsion.

Theoretical Implications

The Los Alamos developments represent a tremendous advance for magnetic plasma confinement theory in general. Many of the immediate consequences of self-organized plasma theory experimentally realized at Los Alamos can be immediately applied to all other magnetic confinement schemes to generate significant improvements in their performance. This in particular applies to achieving higher beta operation in tokamaks.

At a higher level, these results have immediate implications for astrophysics, geophysics, and ionosphere physics. Fundamental questions concerning star structure, the nature of the magnetic dynamo of the Sun and the Earth, solar system formation, magnetic field line reconnection, and the dynamics of the ionosphere geomagnetic *x* point are just a few of the most obvious examples.

But it is at the level of Riemannian relativistic physics that these developments have their most significant impact. The self-organized plasma experiments reviewed in this article intrinsically demonstrate precisely the same character of evolution that Riemann discovered in the case of acoustic shock waves. The projected natural path of evolution of these systems—if provided with the proper boundary conditions—is that of negentropic action. Once this is recognized these self-organized plasmas provide a unique experimental ground for further expanding empirical knowledge of Riemannian relativistic physics. And it is this that will accelerate the rate of development of self-organized fusion systems as well as humanity's real scientific knowledge.

Charles B. Stevens is director of fusion engineering for the Fusion Energy Foundation and well known for his popular articles on fusion technology and science.

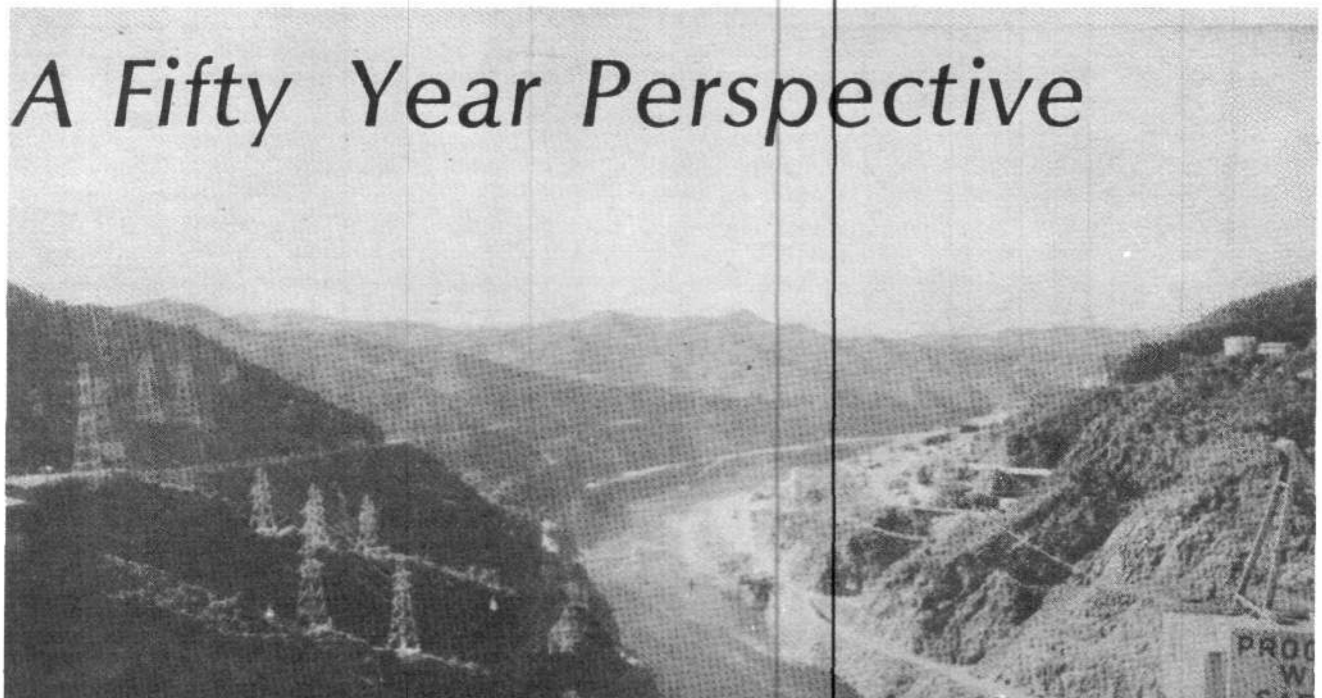
Notes

1. Lyndon H. LaRouche, *The Design for a Leibnizian Academy of Morocco* and *Mathematical Physics from the Starting-Point of Both Ancient and Modern Economic Science*, (New York: Campaigner Publications, 1983). See also a summary of the LaRouche speech given April 13, 1983 at the Fusion Energy Foundation conference on beam weapons in Washington, D.C. (available from the Fusion Energy Foundation).
2. Albert F. Lawrence and W. Ross Adey, "Nonlinear Wave Mechanisms in Interactions between Excitable Tissue and Electromagnetic Fields," *Neurological Research*, 4:1/2 (1982),p. 115; Johndale C. Solem and George C. Baldwin, "Microholography of Living Organisms," *Science*, Vol. 218, (Oct. 1982), p. 229.
3. John Schoonover, "The Fusion Torch—Unlocking the Earth's Vast Resources," *Fusion*, (Dec. 1981), p. 42.
4. Charles B. Stevens, "The Zeta Moves into First Place in Fusion," *Fusion*, (Jan. 1980), p. 54.
5. "An Interview with Adolf Busemann: Pioneer in Shock Waves, Supersonic Flight, and Fusion Power," *Fusion*, (Oct.-Nov. 1981), p. 33.
6. Adolf Busemann, 1962 NASA Sp-25, 1.
7. Harold Grad, "Reconnection of Magnetic Field Lines in an Ideal Fluid," *COO-3077-152, 1978*; also, "Magnetic Confinement Fusion Energy Research," *International Journal of Fusion Energy*, 2:1 (1978), p. 3.
8. D. Wells and P. Ziajka, "Production of Fusion Energy by Vortex Structure Compression," *International Journal of Fusion Energy*, 1:3 (1978), p. 3.
9. J.B. Taylor, *Phys. Rev. Letters*, 33:1139 (1974).
10. J. R. Jarboe, "Steady State Spheromak," Los Alamos National Laboratory Report LA-UR-82-3309.
11. Ibid.
12. C. W. Hartman and J. H. Hammer, *Phys. Rev. Letters*, 48:929 (1982).
13. J. H. Hammer and C. W. Hartman, "Applications of Accelerated Compact Toroids," and Charles Hartman et al., "Acceleration of Magnetized Plasma Rings," in *Proceedings of the Fifth Symposium on the Physics and Technology of Compact Toroids*, Nov. 1982, p. 161.
14. See the special issue of *Fusion* on polarized fuel, Sept. 1982.

Special Report

Asia Can Lead World Economic Revival

A Fifty Year Perspective



PIB, India

"If the world has the wisdom to take practicable measures to escape from the present general economic depression, projects such as those projected here, projects ready to be set into motion more or less immediately, will be essential stimulants for the economies of the community of nations, both within numerous of those nations more directly, and as stimulants for increased volumes of world trade.

"Admittedly, some of these projects and other of the actions proposed, have been energetically supported by others during the course of preceding decades. This record of frustrations does not lessen the practicability of proposing such measures again today. Times have changed. The difference between the past and the present is chiefly that the enormity of those economic and other catastrophes past habits have bestowed upon the world encourages us mightily to consider modifications of those policy-making habits, and to foster a sympathy for great undertakings to a degree wanting during earlier decades."

So stated one of the featured speakers at a conference in Bangkok on 26 October 1983 on "Long Term Economic Development of the Pacific and Indian Oceans Basin" called to discuss the pivotsl role the Asian nations cand and will play in the world economy in the immediate future. At the center of discussion was the proposal to initiate a series of "great infrastructure projects" in the region that would have the effect of focussing and quickening Asian economic development and at the same time providing a powerful stimulus to world economic recovery. The usefulness of such a programme as an avenue for productively resolving various of the knotty political problems in the region—many of the suggested projects are international in character—was also emphasised.

The conference was sponsored by the Ministry of Communications of Thailand, the New York-based Fusion Energy Foundation (FEF) and Executive Intelligence Review (EIR) magazine. *Fusion Asia* Editor Ramtanu Maitra was invited to participate, joining a speakers list that included Minister of Communications Samak Sundaravej, former Secretary-General of the Thai Office of Atomic Energy for Peace Dr. Svasti Srisukh, EIR Chairman Mr. Lyndon H. La Rouche, and Fusion Energy Foundation Research Director Uwe Parpart-Henke. More than 200 were in attendance, representing all sections of the Thai political and policy-making spectrum and including representatives from most every Asian embassy in Bangkok.

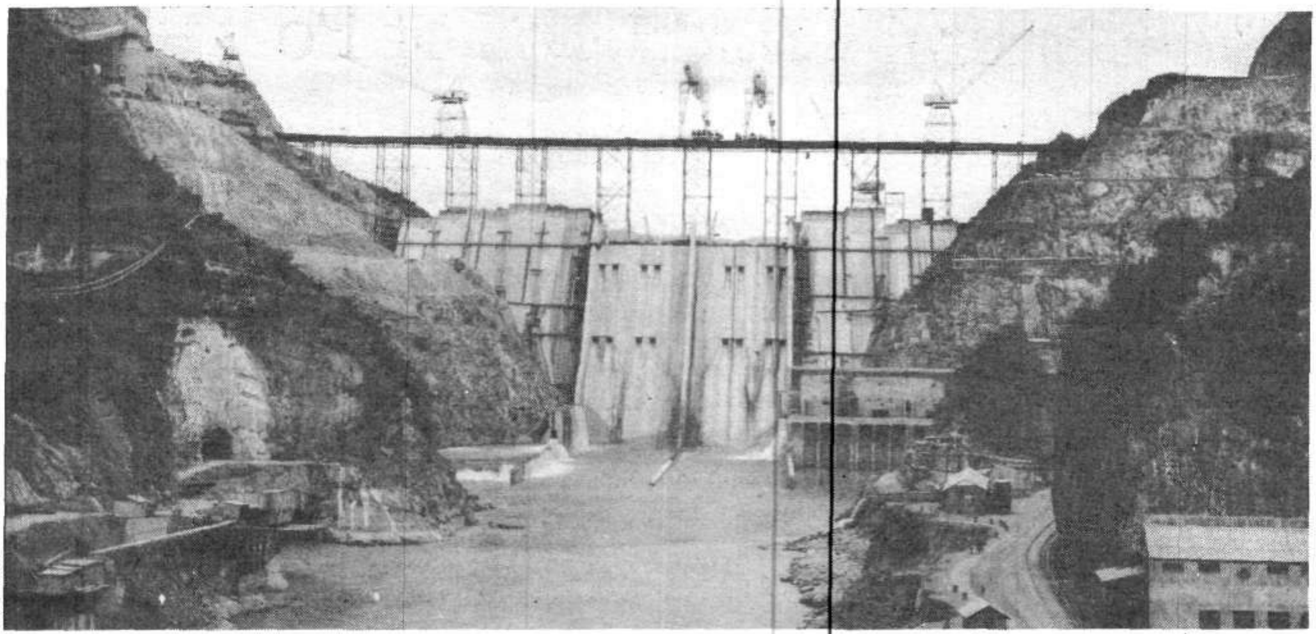
The initiative was that of Mr. Lyndon LaRouche, an American economist who has compaigned for comprehensive international monetary reorganisation and for the launching of large-scale infrastructure projects in the developing sector uniquely suited to effect rapid, in-depth economic growth for the last ten years. The proposal, which LaRouche has elaborated in book form, was significantly inspired by the 1978 "Global Infrastructure Fund" proposal of Japan's Mitsubishi Research Institute. On the basis of discussions during a recent visit to India, Thailand and Japan LaRouche was convinced of the necessity for reviving such an approach. In September EIR organised a similar seminar in Washington to bring the proposal to the attention of policymakers there.

Unique in the proposal under discussion is the broadened perspective which insists that Indian and Pacific Oceans basins be considered as a single unit—a point which seems awkward at first, but which a look at the map and a review of demographic and trade statistics quickly proves to be eminently sound. Also unique is the underlying approach to economic policy-making by which criteria such "great projects" are correctly understood as the essential motors of economic development they in fact are. Proceeding in such a direction would imply a sweeping correction of economic policymaking away from the monetarist, austerity-based recipes prevailing today. Moreover, as LaRouche emphasised in his conference address, motion in this direction in Asia is the surest guarantor of the political-strategic integrity, stability and independence of individual nations and the region as a whole.

Thai Communications Minister Mr. Samak Sundaravej, who opened the meeting, has had a long-term interest in the project to supplement the straits of Malacca with a canal across the isthmus of Thailand, the Kra Canal project, which is viewed as a centerpiece of the proposed infrastructure projects and which was central topic of the Bangkok deliberations. The Kra Canal project was ready to be implemented in the early 1970s but was derailed in a change of government, and has been a subject of controversy ever since. Proponents emphasise the enormous boost to Thailand's national development that would result from creating an entirely new growth area in the southern part of the country. Opponents list a myriad of objections, from the alleged opposition of Singapore to the alleged dangers of using nuclear explosives in construction—a central feature of the most recent project plan for the canal. But in many Thai policymakers' view, as Mr. Samak stated in opening the session, the question to be asked about the Kra Canal project is a very simple one: "Is it possible? If it is, then go ahead."

Dr. Uwe Parpart-Henke stressed in his presentation that the canal was not only feasible, but necessary. "Between 1960 and 1980, imports and exports of the Pacific and Indian Ocean nations grew at almost twice the rate of world trade and increased sixfold—in some crucial categories more than tenfold. By 1982 this had brought the shipping volume through the Malacca Straits up to 40,000 ships a year," Parpart Henke stated, citing the results of a recent FEF-EIR study of the canal project. "Using the most conservative economic growth scenario, this volume will go up to at least 110,000 ships by the year 2000 and again increase tenfold to over 1 million ships by 2020. There is general agreement among experts that even the first of these shipping volumes cannot be handled safely or rapidly by the Malacca Straits...The Kra Canal is not just a feasible, but a *necessary* project."

In the afternoon panel discussion, which included the participation of Dr. Chitti Wacharasindhu, deputy



India's Bhakra Dam, shown here under construction in 1959, gave a powerful boost to industry and agriculture in the subcontinent. Prime Minister Jawaharlal Nehru called the huge project India's "Temple of Progress." The downstream view from the top of the dam is shown on page 55.

permanent secretary of the Ministry of Communications, and Dr. Svasti Srisukh, valuable data on the use of peaceful nuclear explosives (PNEs) to excavate the preferred Route 5A for the canal was provided. Dr. Svasti explained that this route offers the least obstacles and avoids dense population centers. Of the 102 kilometres of canal length, the use of PNEs in excavation has been projected for about 45 km where mountains need to be moved. In a detailed review of the subject, based on the feasibility study on the use of PNEs to build the canal carried out in 1973, Dr. Svasti emphasised that there would be no danger from the use of nuclear explosives either in Thailand or in neighbouring countries. Use of PNEs would save several billion dollars and reduce construction time by two years, Dr. Svasti said.

The work could of course be done using conventional explosive, Dr. Svasti explained, if PNEs proved politically impossible. But it would require a huge quantity of explosives to do the job. Making fun of the pretense of nuclear non-proliferation policies which have blocked the development and use of PNE technology, Dr. Svasti quipped: "This would be good because we'd have to collect all the explosives in the world, so people in other parts of the world couldn't fight".

The broader implications of a project such as the Kra Canal was developed by Ramtanu Maitra as he discussed three other major inland water management projects in the region proposed as the core of the "great projects" package—the Grand Canal project in China, the Mekong River delta development project and the Ganges-Brahmaputra water management project in the Indian subcontinent. "Water must be viewed as a resource," Maitra said. "It not only provides irrigation to agriculture, but it also represents transportation and power generation potential." The harnessing and management of this resource is one of the most basic requirements of infrastructure development whose benefits can be directly translated into leaps in agricultural and industrial productivity. With proper management either the Mekong River delta or the Ganges-Brahmaputra basin could itself feed a majority of the world's population.

Moreover, in the case of Mekong and Ganges-Brahmaputra in particular, Maitra said it is easy to see how such projects can be an impetus to improved political relations with the result, in turn, of improving regional stability and the atmosphere for further cooperation and development. Maitra documented the technical and political progress and potentials of the two projects. While India and Bangladesh are engaged in ongoing negotiations on the pivotal link canal and other aspects of Ganges-Brahmaputra management, he pointed out, the obvious benefits to Thailand, Laos, Kampuchea and Vietnam of implementation of the Mekong River development plans long since off the drawing board should act as stimulus to a new initiative from those nations on this important project.

In the following pages the main elements of the "Great Projects" proposal for Asian development are presented in documentaty form, beginning with an excerpt from one chapter of Lyndon LaRouche's book-length discussion of the proposal. This is followed by excerpts from Dr. Parpart-Henke's presentation at the Bangkok meeting, and by precis of four of the proposed projects. We conclude this Special Report with a fresh and thought-provoking statement of the case for PNEs as an essential industrial technology.

The General Conditions of Policy For Economic Development in the Pacific and Indian Ocean Basins

by Lyndon H. LaRouche, Jr.

The matter of economic development of the basin is situated, functionally and geographically, within the setting of a general, worldwide economic recovery, as we have noted above. That connection is defined in the following summary framework of reference.

Economic development is, by proper definition, a development of the productive powers of labor, which means in this case that our attention is focused on the rate of growth of productive powers of labor, relative to pre-existing levels, worldwide; it follows that the sheer mass of growth, the incremental mass of growth rates, must be concentrated in those areas of the world in which two conditions are met. The first, broadest precondition is the sheer size of the labor force participating in general development. This must be adjusted to reflect variations in rates of participation in such development among sectors of the total population.

The dominant feature of the impact of such development upon world trade is relative increase of trade in capital goods. These capital goods are purchased by developing nations (most emphatically) in exchange for commodity exports plus credit, to the effect that the margins of increases in capital-goods traffic in international trade ought to more or less determine the rates and levels of changes in combined credit volumes and commodity exports from capital-goods-importing nations and regions. In such a pattern of trade between industrialized capital-goods-exporting nations and developing economies, the relative volumes of exports from the former shift from present patterns, to emphasis on both the machine-tool and ordinary categories of capital goods, relatively de-emphasizing consumer goods categories, and increasing the relative weight of machine tool categories in respect to other capital goods categories.

This shift increases the premium upon high-speed ocean freight.

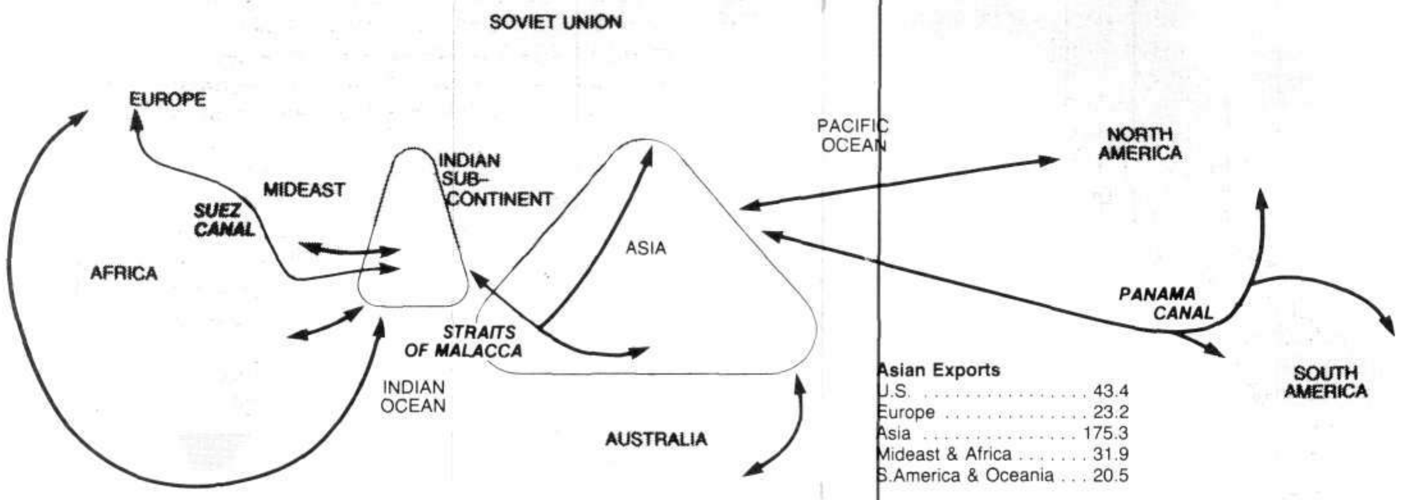
The ABCs of freight policy are the matter of balance between cost-per-ton-mile of delivery from producer's shipping-door to consumer's receiving-door, and the product of lapsed time for such transport and the value-per-ton of freight moved. Under projected conditions of general economic recovery, several interrelated shifts in composition of trade must occur, shifts which shift trade toward higher values per average ton shipped. In respect to raw materials trade from, for example, developing economies, there is a shift toward export of goods in a relatively more advanced stage of refinement, and from raw materieals, to intermediate commodities incorporating such processed materials. Among imports from industrialized into developing nations, there is an increase in the ratio of capital goods to consumer goods. At the same time, there is increasing capital-goods trade among developing economies

Applying elementary "center of gravity" calculations to the *rate of growth* of *value-ton-mile* trade among economies, the importance of the combined basin of the Indian and Pacific oceans stands out immediately. Here lies the center of gravity of the highest rates of growth in world trade relative to existing levels (over the medium term to long term, after start-up). Cumulatively, this must emerge as not only representing the highest rate of growth of such trade, but as dominant in respect to absolute volumes of trade.

This obliges us to examine the development of the world's economy in terms of principal ocean basins: Indian-Pacific, Mediterranean, North Atlantic/North Sea, South Atlantic, and Caribbean. We must examine the growth of the economies of the world in terms of growth of the world trade within and among the indicated basins. The center of gravity estimates indicated above, focus our attention upon strategic choke-points. The choke-point from the Mediterranean into the Indian-Pacific basin is the Suez Canal. From the South Atlantic into the Indian Ocean basin it is the Cape of Good Hope. From the North Atlantic and South Atlantic, through the Caribbean, into the Pacific Ocean, it is the Panama Canal. Within the combined Indian-Pacific basin, it is the Straits of Malacca, presently a crippling choke-point, which could be remedied only by a high-speed, sea-level canal through the Isthmus of Thailand.

This is the general world map of the required approach to projected worldwide économic developent, and to economic development of the basin itself.

Then, as we focus upon the intenal development of the basin, we enlarge the scope of infrastructural development, adding to infrastructural projects and programs directly bearing upon general world trade the major projects and programs of the relatively greatest, beneficial impact upon the economies of nations and regionalities of the basin as a whole. Our adopted approach to this matter of projects proposed is both scientific and political, in the spirit expressed by the Mitsubishi Research Institute's Great



Asian Exports	
U.S.	43.4
Europe	23.2
Asia	175.3
Mideast & Africa	31.9
S.America & Oceania	20.5

Indian Exports	
U.S.	0.2
Europe	12.2
Asia	25.3
Mideast & Africa	19.4
S. America & Oceania	0

Indian Imports	
U.S.	5.4
Europe	4.0
Asia	8.9
Mideast & Africa	30.8
S. America & Oceania	1.6

Asian Imports	
U.S.	126.6
Europe	12.2
Asia	194.4
Mideast & Africa	313.6
S. America & Oceania	202.9

Asia: Center of Gravity of World Trade

The Indian and Pacific Ocean basin is already the center of gravity of world trade, as the map indicates. The trade volume for exports and imports, shown here in millions of metric tons, was compiled from the United Nations country statistics for 1980.

Over the past 20 years, the tonnage of imports in this area increased from 171.6 to 912.9 million tons, while exports went from 81.8 to 540 million tons. The compounded rate of growth of two-way trade for this period was 9.1 percent per year. The per annum growth rate in trade in this period is 80 percent higher than the rest of the world's, 90 percent higher than that of the United States, and 150 percent higher than that of West Germany.

A few more statistics make the point: 49.9 percent of all iron ore shipped in the world goes to Asia, (42.5 percent of it to Japan), 44.5 percent of all coal, and 33.9 percent of all grain. In all, 2 out of every 5 metric tons moving in the world are going into or out of Asia.

Infrastructural Projects proposal. The political policy we have adopted is that each project proposed in the listing should stand on its own merits economically, but that the package of such listed projects, as a whole, should embody the principle of equity among nations and peoples, that each part of the basin should gain an important benefit from the package of projects as a whole. . . .

Policy: Social Composition of Labor Force

. . . *The goals of development must be stated in terms of effects broadly reflected in shifting composition of employment of the total labor force, as we have elaborated the principled considerations in the preceding chapters.* The accompanying chart indicates the varieties of data which must be assembled, and their determination refined, both for projecting programs of development, and for monitoring the performance of policies. This approach provides an essential part of the basis for developing a much-needed, sweeping replacement for presently prevailing methods and practices of national-income accounting. The chart is merely preliminary, illustrative, but it serves to illustrate the direction in which this aspect of the work must proceed.

In this connection, we require targets for new compositions of employment of total labor forces, for the global economy, for the basin, for regions within the basin, and particular national economies. Goals to this effect should be developed as suggested goals to member nations, not as "conditionalities," but as a matter of scientific services. Each nation should adopt its own goals, taking into account the proposals and the scientific considerations employed to develop the proposals. The adoption of such goals by each nation provides the needed basis of reference for shaping policies of cooperation.

Broadly, there can be no economic development of the basin unless the majority of the population of the basin undergoes a progressive shift away from both "pre-industrial" and "post-industrial" compositions of labor-force employment, in the direction of a range of distributions of such employment-composition consistent with modern technology and corresponding increases of potential relative population-density.

The technological correlatives of such required shifts in composition of employment enable us to foresee with relatively great accuracy what must be the categorical features of economic policy for the basin.

The first of these technological correlatives is development of *basic economic infrastructure:* (1) *Fresh-water management systems,* including their role in inland transportation; (2) *Transportation,* including ocean transport, ports, railway systems, air-transport systems, highway systems, and efficient interface among these systems and the warehousing and related materials-handling features of transportation as a whole; (3) *Energy production and distribution systems;* and (4) *Urban industrial infrastructure.*

The pivotal feature of general programs for development of infrastructure is energy systems. The possibility of assimilation of modern technology, and more advanced technologies, into agriculture and industry, and development of water management, transportation, and urban infrastructure is bounded by the constraints embedded in existing capacities of energy's production and distribution. Energy systems are defined chiefly in respect to: (1) kilowatts per square-kilometer, (2) kilowatts per-capita [for total population, total labor force, and operatives, respectively] (3) energy-flux density of prime generating sources, and (4) effective distribution. The modes of supply of energy are chiefly: (1) mechanical, including hydrodynamic, (2) chemical combustion, (3) nuclear, and (4) chemical and biological, including produced fertilizers for agriculture.

The effectiveness of energy sources is determined chiefly by three considerations: (1) supply of the resources; (2) the energy-flux density available with the resource employed; and (3) the available coherence of the energy produced. Generally, solar and biomass combustion are not acceptable on any of the three grounds indicated. Combustion of fossil fuels in modes other than magnetohydrodynamics (MHD) is qualitatively inferior on the three counts indicated to nuclear processes, especially to thermonuclear processes. Hydroelectric generation is indicated for instances in which conditions (1) supply and (2) potential are met, but in most instances, hydroelectric sources should operate in conjunction with "supplementary" nuclear sources, and are recommended most strongly as included features of large-scale water-management systems. In the coming period, fission sources, increasingly supplemented and later entirely superseded by thermonuclear, must be the leading feature of energy-generation policy. It would not be possible to supply supplies of added energy adequate to approach the requirements of the developing sector, most emphatically, without primary emphasis on unleashing and expanding potentials for fission generation of electricity and process heat today, and proceeding as rapidly as possible toward progress in successively more advanced versions of controlled thermonuclear processes.

Without this policy, tens of millions or some mulitple of that must die of increased morality rates, for lack of energy supplies adequate to prevent this.

The principal added souces of energy production to be considered are complexes of central plants. Since nuclear-energy production must supply the largest relative increment, and since such nuclear plants are broadly comparable in scale to modern energy-generating plants using coal, petroleum, gas, and so forth, we are able to foresee some of the principal features of energy development, features which characterize the greatest portion of energy-supply development for the decades ahead. In the typical, normalized case, the energy supply will be generated by complexes of not less than two to four nuclear plants, each plant ranging in output capacity from 250 megawatts to between 1.2 and 1.5 gigawatts.

This brings us immediately to the matter of urban infrastructure. The generation of an economical supply of energy requires that this be concentrated in relatively large units of output, not less than 1.0 to 6.0 gigawatts per area in which the generation occurs. This concentration is that of an urban industrial area. For reasons of desirable economy in distribution of energy to rural areas, and for analogous reasons of cost and time of transportation of other goods, development of rural populations implies the distribution of urban centers among the areas of rural habitation, centers characterized by not less than 1.0 gigawatt energy generation into electrical grids.

For these combined reasons, urban centers are normally to be located at nodal points of optimal transportation and energy-distribution grids, with a premium on locating sites which enjoy potentialities of ocean and other water-borne transport. (The ocean mouths of large rivers appear therefore to persist as a good urban-site policy for radiating the development of society, from the beginnings of civilization in prehistoric times, to the present.

The development of the transportation and energy grids, including the projection of grids allotted for future development, defines the skeleton for the process of urbanization of developing economies as progress in per hectare and per capita outputs in agriculture energizes a natural migration from rural to urban modes of employment.

After infrastructure, in developing nations with relatively *high ratios of rural population, the development of agriculture* has the relatively greatest impact upon development of the economy as a whole. During the postwar period, emphatically the recent decade and a half, the relative importance and general benefits of this priority have been undreplayed, as international lending institutions' "conditionalities" policies and correlated forces have influenced general practice. The issue of increasing the output per hectare and per farmer through aid of advances in applied technology is not merely providing adequate food supplies, agricultural fiber, and export earnings; the issue is that of assuring these requirements' fulfilment while also reducing the percentage of the total labor force required for necessary production of raw materials. The number of

CHANGES IN LABOR FORCE MAKEUP (%) OF SOME DEVELOPING COUNTRIES[1]

	1950	1960	1965	1970	1975	1980
Mexico						
Agricultural	58.3	54.1	45.8	37.5	34.7	30.6[2]
Industrial	18.5	22.2	24.0	25.8	27.7	30.9[2]
Services	23.2	23.7	26.2	29.5	37.6	40.5[2]
Brazil						
Agricultural	59.9	54.0		43.6		32.5
Industrial	26.9	29.9		33.5		46.9
Services	5.3	6.4		8.9		12.0
Argentina						
Agricultural	19.4	17.5		16.7		12.5[3]
Industrial	43.4	44.0		45.7		38.8[3]
Services	37.3	38.6		37.6		48.5[3]
Philippines			(1966)	(1971)	(1976)	
Agricultural			56.9	48.6	50.0	
Industrial			19.0	19.4	17.4	
Services			23.7	27.0	27.3	
India		(1961)		(1971)		
Agricultural		69.5		69.7		
Industrial[4]		16.1		13.1		
Service		14.5		17.2		
South Korea			(1966)			
Agricultural			53.8	48.2	44.0	32.2
Industrial			12.4	16.4	22.5	27.2
Services			29.0	33.7	33.5	41.1
Egypt						
Agricultural		53.9	51.8	47.4	44.4	37.9
Industrial		17.3	19.9	21.4	22.0	23.8
Services		28.8	28.3	31.5	33.6	35.9
Nigeria						
Agricultural		70.8		62.1		
Industrial		10.4		13.8		
Services		18.8		24.1		
Kenya						
Agricultural		94.5		82.1	76.9[2]	
Industrial		9.6		7.1	6.7[2]	
Services		9.1		10.8	11.8[2]	

1. Series are generally not completely comparable between countries due to differences in definition.
2. Updated from previous years by rates of change in a noncompatible series.
3. From a different source than previous figures, not necessarily comparable.
4. For India, 'Industrial' includes workers in household industries.

Sources: La Economia Mexicana en Cifras, Nacional Financiera SA 1978; Jorge Bazua, pers comm; Anuario Estatistico do Brasil, 1981; Sistema de Cuentas del Producto e Ingreso de la Argentina, Banco Central de la Republica de Argentina, 1975; Anuario Estadistico de la Republica de Argentina, 1979-1980; Statistical Yearbook for Asia and the Pacific, United Nations, 1979; Statistical Outline of India, Tata Services Ltd, 1980; Economic Statistics Yearbook, Bank of Korea, 1979 and 1982; Africa South of the Sahara, Europa Publishers Ltd, 1980-81.

There can be no economic development of the basin unless the majority of the population undergoes a progressive shift away from both preindustrial and postindustrial composition of labor force employment, in the direction of a range of distributions of such employment composition consistent with modern technology and corresponding increases of potential relative population density.

urban operatives sustained per farmer, in terms of food and fiber requirements, is the rough measure of margins for national and regional economic development.

The development of the infrastructure and industrially produced materials required by the development of agriculture generates a large part of the "demand" through which capital-goods industries and basic industries are fostered. This aids in promoting a policy of increasing the capital-goods sector of production more rapidly than consumer-goods employment. Water management, energy, transportation, and urban development, which must emphasize the development of agriculture in the course of shifts away from "preindustrial" social composition of employment, help shape a healthy pattern of development of urban life.

The peril to be avoided, in this respect, is the folly imposed by the United States and other influences upon Ibero-American nations, for example. It was argued that "import substitution" required emphasis on promoting urban consumer demand through production of consumer goods. These wages would, it was argued, expand markets for consumer goods generally, and the earnings of such industries, it was also argued, would foster investment in infrastructure and capital-goods industries at a later point, as well as sustaining markets for agricultural goods. This was the "demand-pull" doctrine of economic growth and prosperity popular in may quarters. The result was disastrous.

Urban growth associated with such policies fostered the trappings of prosperity in some portions of the urban population, while imposing upon the market a level of consumer goods and services presented above the earned consumer purchasing power generated, on the average, by the economy as a whole. It was the lack of investment in agricultural development, in capital-goods industries, and essential elements of infrastructure which caused the indicated policies to foster the spectacle of a growing gulf between an apparently prosperous urban middle class and a burgeoning of combined rural and urban poor: Social instabilities and apparent "overpopulation" were the included consequences.

An adequate growth of per capita consumer income is obviously required. The issue is, at what rate can this be increased, and the increase sustained by the economy over extended periods? The emphasis must be upon those sectors of employment whose development fosters the highest relative rate of increase of average productivity, output. These area are, as indicated, improvement of technology of agriculture, development of infrastructure, and capital-goods production. It is from these three areas that advances in the per capita output, and hence income, of the entire population chiefly originates: these are the three areas which most directly, most efficiently, transmit advances in technology to the economy as a whole.

The final among the fundamental ingredients of economic growth is the composition of social infrastructure, the most directly "economic" of the elements of overhead-expense of society: (1) *education*, broadly, inclusively classified; (2) *medical*, broadly, inclusively classified; (3) *scientific and engineering services, broadly, inclusively classified*, to include but not limited to the research-and-development component to which we assigned the proposed, 5 percent target figure. Except for the essential administrative activities of enterprises, and the essential administrative, law-enforcement, and military functions of government, it is urgent that other categories of overhead expense, including labor-intensive forms of unskilled and semiskilled "services," be constrained to the effect of limiting the growth of employment in overhead expense cateogries as a whole. We have already indicated the principal arguments on this point in the preceding chapter. To restate the kernel of the point, in summary, every nonessential instance of overhead expense is a double cost to the society: a person who is not producing, and a person whose employment and activities represent a tax upon the economy, an inflationary tax. Unemployment has an impact akin to that of redundant overhead expense.

The remainder of the urban labor force, after deducting infrastructure, raw materials, and overhead expense, as categories, from the total labor force, is usefully apportioned:

(1) **Capital Goods**
  (a) Machine-tool category
  (b) Other capital-goods
(2) **Consumer Goods**
  (a) Consumer durables
  (b) Consumer non-durables
(3) **Basic and Intermediate Goods**
  (a) Basic industry
  (b) Intermediate goods

of which the final category includes production flows supplying both the first two categories. It is the desired ratios of employment among these categories which is the first consideration; suitable industries should be selected for "hiring" (investment commitment) to fill out the capacity defined by target ratios of social composition of employment.

The priority consideration is import of technology. This is a consideration as applicable on principle to an industrialized economy as for an economy in the "pre-industrial" or "semi-industrialized" categories. While it is desirable that consumer goods be produced within the economy, rather than imported, the development of industries incurs capital investment. If the capital investment required for consumer industries aggregates to a level at which capital goods industries are constricted in development, the result is more or less injurious. It is the ratios of employment which must be overriding. This points our attention to some key considerations.

Each kind of industry is associated with a specific division of labor in production, a division of labor which varies in complexity with levels of technology employed, to the effect that the combined division of labor of both operatives and the division of labor combined in multifunction machines used by individual operatives, increases with advances of technology. This set of considerations determines economics of scale, to the effect that the variety of industries within a labor force of finite size is limited in number by the number of operatives each industry minimally requires to be competitive.

This defines a combination of economic bottlenecks in both capital-goods and other industrial production, and of the combined varieties of production, for an internal economy of finite size. These implicit bottlenecks define interdependency among economies; as the level of technology in the world advances, the global economy becomes increasingly interdependent. The policy problem thus posed is, chiefly, how to reach agreements on division of labor in production for export among states without impairing the sovereignty or desire for reasonably substantial self-sufficiency in basic necessities among nations. This consideration is a leading factor in creating the need for large-scale economic-development cooperation among nations of regions of the world.

The one added general observation, useful and perhaps required at this point, is that the policy of industrial development must break with the frequently stated or implied opinion, that developing nations should concentrate on industries which industrialized nations seek to abandon to "cheap-labor markets," either in entirety or in substantial part. Such developments are not to be excluded, nor necessarily despised, but they should not become the predominant pattern in industrialization as a whole. There are two, perhaps seemingly contradictory policies to be taken into account, to acquire a correct overview of the problem.

It were desirable that long-term investments in industry in developing nations tend to "leapfrog" the average levels of technology for that category of industry in industrialized nations. The highest relative productivity is the highest, in whatever national economy it occurs. The relatively highest productivity means the relatively highest contribution to the average productivity of the entire economy, and to the prospective rate of growth, therefore.

Monetary Reforms Required

The general outlines of proposed, required reforms of the international monetary system are adequately specified in the book cited earlier here, *Operation Juarez*. Therefore, we limit ourselves here to listing a succession of basic principles.

The opposition to the practice of usury as both immoral and destructive, a consistent republican view in European civilization over more than 2,500 years, is expressed in today's world not only by usury per se, but as a fundamental conflict between two opposing kinds of monetary orders. The paradigms for a monetary order based upon and dominated by the principle of usury include the pre-1914 London gold-exchange system, the Versailles monetary order pivoted upon the Weimar reparations debts, and the postwar Bretton Woods System as now dominated in its senility by institutions including prominently the Bank for International Settlements. The paradigm for a republican monetary order is the statement of policies set forth in U.S. Treasury Secretary Hamilton's famous Reports to the Congress, on credit, a national bank, and manufactures.

The political essence of the present international monetary crisis is the challenge of choosing between a world economic order resembling the looting practices associated with Hjalmar Schacht, and the preconditions of general economic recovery supplied by creating a new international economic order not inconsistent with the monetary and economic policies of the American System. Any other view of this matter misses the practical point.

In a republican order, the following leading features of monetary policy prevail.

The money supply is limited to the currency notes issued either by treasuries of governments of sovereign states, or by national banks acting as agents of those governments.

The new issues of such currency notes are placed in circulation through the combined lending and rediscount functions of national banks.

Lending of new issues is limited to purposes which governments permit for loan of these issues. Except for overriding requirements of national interest, as emergency mobilization for national defense or other emergencies, these issues are loaned at low nominal borrowing costs for investments which directly promote increase of the productive powers of labor in the production of useful, physical goods. This may occur either as a direct loan by a national bank, or as national-bank participation in a loan otherwise subscribed by the private banking system.

So, money is placed into circulation through investments which expand and increase productivity in the employment of operatives. *It is in this fashion that monetary demand is generated and is chiefly regulated.*

Republics provide efficient methods for regulation of good order in the conduct of business by private banks. Lending by banks is limited to determined percentages of the total deposit of currency plus specie actually deposited with those banks, as combined deposits of investors and other bank depositors. The "Keynesian multiplier" is choked.

The function of government issues is to supply adequate supplementary lending power, by combined resources of the national bank and the private banking system. Inasmuch as possible, it is desirable that this lending of government issues occur as participation in loans of approved categories by the private banking system. This strengthens the private banking system, reduces the administrative burdens of the national bank respecting local features of the economy better administered by the private banks, and fosters a participation of deposited savings in those categories of investment which contribute relatively most to expansion of output and improvement of the productive powers of labor.

In commerce and investment among nations, it is required that stable and fixed parity-values of national currencies prevail. This stability is fostered within each nation by aid of the currency and banking practices identified above. These policies are explicitly and efficiently anti-inflationary modes of economic growth, on condition that significant rates of advancement in available technologies are provided. These measures implicitly require the added measures of a gold-reserve system in support of fixed parities of currencies in international commerce and investment. This permits low nominal borrowing costs to prevail, and thus provides the indispensable climate for high levels of trade and investment among nations.

This requires a matching policy of taxation. In general, it is necessary that accumulations of capital in productive investment and closely related ventures be encouraged, and accumulations through financial speculation, ground-rent-price speculation, and commodity-price-fluctuations speculation, be discouraged. The investment-tax-credit device, to reward entrepreneurs and savers for investments which foster increases in the average productive of labor, is perhaps a superior choice of measure in aid of the stipulated economic object of taxation policies.

It is, of course, somehwat more than merely desirable, that current-account expenditures of governments, as distinct from capital-account expenditures, be paid out of a general revenue supplied entirely by taxation.

By aid of these monetary-policy measures, high rates of noninflationary economic growth can be promoted and sustained indefinitely, without prompting reappearance of a "business cycle."

Kra Canal Is Cornerstone of Asian Development

by Uwe Parpart Henke

As far back as 1793, the younger brother of King Rama I of Thailand (Siam) had proposed to dig a canal across the peninsula of Thailand south of the Isthmus of Kra, connecting the Lake of Songkhla and the South China Sea with the Indian Ocean. The motivation at the time was to facilitate military and naval operations against frequent Burmese invasions. However, in spite of numerous military and, even more important, commercial advantages, no such canal has been constructed to date as the project remains a subject of political controversy.

From the standpoint of facilitating greatly increased trade and rapid ocean transport between the Indian Ocean basin and the Pacific Ocean basin and, more broadly, between the Western world and the countries of Southeast and East Asia, there is, however, no question about either the urgent need for the Kra Canal or its pivotal role in the economic development of Thailand and the entire region. The Straits of Malacca, which now handle most of the relevant traffic, are highly congested and will become quite inadequate by the end of this decade based on even modest projections of increased trade flows.

A relatively recent feasibility study for the Kra Canal, commissioned in the early 1970s by Mr. K.Y. Chow of the Thai Oil Refining Company, can serve as an excellent basis for initiating the project as soon as Thai government approval is secured. Of course, the feasibility study in question, carried out by engineers and planners of Tippetts-Abbett-McCarthy-Stratton (TAMS) and Robert R. Nathan Associates, Inc. (RRNA), in collaboration with Lawrence Livermore National Laboratory of the Uni d States and submitted in September 1973, is now dated and requires extensive review. Such review would principally have to evaluate economic feasibility and financing proposals. The engineering conclusions of the TAMS-RRNS study, in the view of this writer, remain valid, though in certain instances very recently developed technologies could shorten construction time and improve final performance.

The Kra Canal Project, as detailed in the TAMS report, differs conceptually from earlier major canal projects with which it would reasonably be compared, for example, the Suez and Panama Canals. The transport distance saved by building the Kra Canal—about 900 miles—would not by itself appear to justify the large expenditures in excavation and operating costs. There are two other principal factors which define the overall importance and viability of the project. These are: (1) the already mentioned growing *inadequacy of the Straits of Malacca*, and (2) the *industrial development potential* based on construction of *deep sea ports* at one or both of the canal outlets.

The Straits of Malacca are used by well over 50,000 ships a year and further significant increases in traffic are inevitable. Thus the Kra Canal could be expected to attract all excess traffic from the Malacca Straits as well as traffic which assigns a premium to speed. Emphasis on speed, as will be explained below, is a major reason why the TAMS study selected a canal route well south of the actual Kra Isthmus. This route, labeled 5A (see map), makes possible the construction of a *sea-level canal without locks* through which even large (up to 500,000 dead weight ton or dwt) tankers could pass at normal speed. The integration of one (or possibly two) deep sea ports and associated industrial development zones with the Kra Canal proper can be expected to become the single greatest long-term economic asset of the entire project.

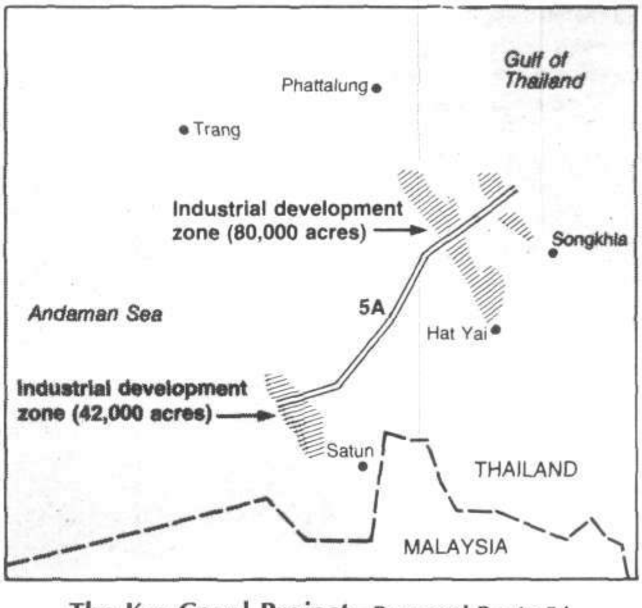
Taking the experience of the "Europort" of Rotterdam at the mouth of the Rhine River as a model, an "Asiaport" conjoined with the Kra Canal could become not only a major trade center for Southeast Asia, capable of eclipsing Singapore, but also has the potential—as proved by the Rotterdam and similar examples—of serving as a focal point for major industrial development.

A major included *strategic factor* also deserves the attention of Thai policy makers. Contrary to some reported opinion and concern that a canal through the southern part of the Golden Peninsula would have negative security implications, severing the ethnically and religiously ill-integrated southernmost part of the nation from the rest of the country, the opposite consequence would be the projected outcome. The canal complex as a major industrial growth-spot would function as an integrating and unifying factor, joining together the southern, central, and northern provinces in a large common endeavor capable of inspiring the entire nation, uplifting the economic condition of the southern population, and thus reducing the potential for dissatisfaction and dissension, while putting Thailand into a potentially commanding strategic position vis-à-vis its South and Southeast Asian neighbors.

Route Selection and Canal Specifications

Any canal-design study must give at least a preliminary answer to two basic questions: First, what size ships and what maximum volume of traffic are to be accommodated? Second, given preliminary answers to these questions, and given the geographical and geological constitution of the general area under investigation, what is (are) the optimal canal route(s) from the standpoint of these considerations.

(1) Ship sizes and traffic volume projections. It is clear that tankers of at least 500,000 dwt must be accommodated, and handling of larger tankers may be desirable. Maximum safe canal transit speeds with respect to the land of about 7 knots (13 km/h) for ships of this size represent the presently established international standard; in the view of this writer, which differs from that of the TAMS study, a two-lane canal is necessary. The assumption that one lane, handling



The Kra Canal Project—**Proposed Route 5A**

The Kra Canal would save about 1,200 miles in shipping transport in Asia. It would also link the Indian Basin, which includes Sri Lanka, Pakistan, India, and Bangladesh, with the Pacific Basin nations. India now has very little trade with Asia, with the exception of Japan. It is essential to link up India's skilled scientific manpower and capital-goods production with the fastest growing region in the world.

mainly west to east traffic, is sufficient is based on the untenable premise that for a long time to come the export potential of the East and Southeast Asian nations will be small relative to Western imports.

The canal should preferably be sea level without locks, must accommodate drafts of at least 100 feet (fully loaded supertankers); that is, be at least 110 feet deep, and have a bottom width of approximately 500 meters. The alternative to one rather wide two-lane canal would be two one-lane routes of about 200 meters width each.

(2) Route selection. Extensive geographical and geological investigations have been carried out to find the optimal route for a sea-level canal of the above design specifications. Included in these investigations were considerations concerning required canal crossings for railroads, highways, and utilities. Relative excavation costs and, in particular, the feasiblity of nuclear excavation methods were prominently taken into account.

The preferred route settled upon by the TAMS-report (route 5A—see map) would extend from about 30 km north of the city of Satun to the Gulf of Thailand. The total canal length through land for this route is 102 km, with sea approaches of 50 km in the west and 70 km in the east respectively. This is the shortest possible route for a sea-level canal, minimizes excavation costs, and provides for the best possible sites on either end for harbor and industrial development. Construction time for route 5A using conventional excavation methods is estimated to be 10 to 12 years; partial use of nuclear excavation would cut both construction time and cost by at least 40 percent.

'Asiaport' and Industrial Zones

The construction of major deep sea port facilities and associated industrial development zones at either end of the Kra Canal is both feasible and highly desirable. However, phased port and industrial development, concentrating initially on the eastern canal outlet, appears to be the best strategy at this point.

This involves, in particular, a most interesting concept first proposed in the early 1970s by Mr. K.Y. Chow. Since most Southeast and East Asian ports with the exception of Hong Kong and Singapore are, at present, ill-equipped to handle large cargo vessels and could only be enlarged at very high cost, a port facility at Songkhla could rapidly develop into a major transshipment center for the entire region, capturing a very substantial portion of transshipment now handled by Hong Kong and Singapore.

This development, however, would only be phase 1 and should rapidly be followed up by construction of a comparable facility at the western canal outlet. Even in the initial planning stage, both ports must also be laid out to handle not only transshipments, but also the subtantially greater berthing requirements that will arise out of area industrial development. The pattern of such industrial development requires intensive detailed study to be coordinated with existing Thai government plans for eastern seaboard development and construction of a deep sea port at Sattahip.

One possible outline pattern of industrial development for the Kra Canal Complex would look as follows:

(1) Initial development of industries and servicing facilities supportive of the canal and transshipment port projects. This would from the outset have to involve dry-dock and shipbuilding facilities, building a modern fleet of rapid feeder vessels as specified above. Phase 1 development must also take into account the immediate as well as long-term power requirements of the Canal Complex. If nuclear excavation is used, then the right kind of expertise would already be assembled in the region to consider construction of one or several nuclear power plants. Ideas going back to the mid-1960s for nuclear-industrial complexes should be reviewed in this context.

(2) Phase 2 should envisage the development of large and basic heavy industries developed both as an offshoot of the canal construction itself and as back-up for the proposed shipbuilding project—iron and steel as well as basic capital-goods industries as indicated.

(3) *In an environment already shaped by nuclear excavation and power plant development,* having assembled the required advanced engineering and scientific manpower, the exciting possibility arises of developing a modern nuclear-based high-technology complex. Lawrence Livermore National Laboratory experts have suggested that the world's first nuclear isotope separation plant of a significant scale might become associated with the Kra Canal Complex. *Recent developments in laser technology would in* that same context point to the possibility of developing new high-energy laser-based industries.

Reviving China's Grand Canal Project

by Gregory Buhyoff

Work has recently begun on a large-scale project to modernize an ancient system of canals joining China's greatest river, the Yangzte, with the Yellow River and other major rivers and lakes of northern China. The south-north water diversion project centers on the modernization of the famous "Grand Canal," an ancient artificial waterway over which grain taxes were once shipped to the northern imperial capitals from the rice-growing regions of the south. The project could become the major artery in a badly needed network of domestic waterways joining the northern and southern parts of the country, as well as provide a water-control and irrigation system to divert excess water from the Yangzte valley river system to the dry north.

Since all of the major rivers in China run from east to west, commerce between the northern and southern regions of China has historically been difficult. The Grand Canal was the first important transportation link between the north and south, connecting the Yangzte, Huai, Yellow, Wei, and Hai river systems, constituting an important practical and symbolic link between northern and southern China. The Grand Canal, or Da Yunhe as it is known to the Chinese, was one of the greatest public work projects of its time, comparable, in terms of manpower and materials, to the Great Wall. It was built in sections with the major work carried out under Sui Emperor Yang Chien during the late 6th and early 7th centuries and later in the 13th century under the Yuan regime. It stretches approximately 900 miles from the rich rice-growing regions of the Yangzte River valley to the outskirts of Peking.

Over the centuries sections of the canal fell into disrepair and little work was done to make it capable of serving the needs of a modern industrial economy. Today, despite the introduction of rail and air transport, China remains critically deficient in its ability to transport goods from the north to the south and vice versa.

The Grand Canal project was recently revived by the Chinese government as part of a comprehensive plan to modernize China's domestic transport system. The project had originally been proposed in 1978, but was one of many large infrastructural projects to fall victim to the 1979–1981 "economic readjustment" which emphasized fiscal restraint. The project was resubmitted by the Ministry of Water Conservation and Electric Power and approved at last December's meeting of the National People's Congress. It is now considered one of the most important large-scale projects in the New Five Year Plan, and is one of the keys to China's goal of quadrupling agricultural and industrial production by the end of the century.

The primary objectives of the project are:

(1) To increase transport capacity, particularly the means to move large amounts of coal from soon-to-be exploited mines in the northern provinces to Shanghai and other industrial cities for energy production and export.

(2) Water diversion from the Yangzte River to the northern cities suffering critical water shortages.

(3) To provide, in conjunction with smaller canals and river systems, a means to control water supplies for irrigation in the parched agricultural regions of the north China plain.

Though only the first stage of the project, dredging and widening of the 200-mile section of the canal between the cities of Yangzhou and Xuzhou, has been approved definitively by the State Council, the Grand Canal project is reportedly being considered on the basis of a 10-year, two-stage perspective. However, because of the economic debate that continues to divide the Chinese leadership, the scope of this, like a number of other key infrastructural projects, remains undecided.

The Proposed Hangzhou-Peking Canal

As shown here, China's major rivers run from east to west, which historically has made commerce between the northern and southern regions difficult. The ancient Grand Canal, which the Chinese call Da Yunhe, was built in the late sixth century and extends for 900 miles. The modernization project outlined here is key to China's economic growth.

The Mekong River Basin: Potential World Breadbasket

by Peter Ennis

Prior to the Vietnam War, the Mekong River basin was one of the world's most fertile breadbaskets, producing a sizable amount of agricultural products for export, despite the lack of the most basic elements of modern agricultural production. Now, after 35 years of continuous war in the region, production lags behind the most minimal of potentials. The water resources of this huge river go virtually unutilized, with much of the water flowing through the Mekong delta into the South China Sea. Because of the lack of capital investment, there is very little irrigation in the entire basin. There are many canals, but they are largely for drainage and water transportation, not irrigation.

Four riparian countries form the watershed of the Mekong River: Kampuchea, Laos, Vietnam, and Thailand. The Lower Mekong basin covers more than 600,000 kilometers, comprising almost the whole of Laos and Kampuchea, one-third of Thailand, and two-fifths of southern Vietnam. Were these countries to join together to harness the power of this resource, it would not only provide a foundation for their modernization, but it would provide a context for the settlement of the political tensions that continue to plague these nations.

Plans for the development of the Mekong River basin have existed since the late 1950s. Studies have been carried out by United Nations-sponsored task forces, the U.S. Bureau of Land Reclamation, and other organizations; yet for political reasons the plans have not been implemented. The most comprehensive plan to date for the development of the Mekong River basin was drafted by a United Nations team, and is titled "Report on Indicative Basin Plan for the Lower Mekong Basin." The recommendations presented here are largely based on the United Nations study.

A Plan to Control the Mekong River

A program for developing the Mekong basin must address the serious lack of transportation infrastructure in the region, the near-total lack of mechanized agriculture, and the problem of torrential rains during the May-September monsoon season alternating with a very dry climate for the rest of the year.

The key question is how to control the waters of the Mekong, not a very difficult or expensive task. The main stream of the river could be controlled with two dams, one at Pa Mong, and one in Kampuchea, at Stung Treng. Water control would allow use of high-yield varieties of rice, which depend on precise control of water supplies, fertilizer use, and so forth. Vietnam, which now produces some 5 million tons of rice per year, estimates it could produce 20 million tons under such conditions.

Two additional dams would be important as a source of electricity generation: the Sambor dam in Kampuchea and the Upper Thakhek dam in the area of the Thailand-Laos border. These four dams, all on the main stream of the Mekong, would be able to control flooding, provide irrigation, and thus make possible double- and triple-crop agriculture in the delta.

There is an additional proposal to build a dam at the mouth of what is called the Great Lake in Kampuchea, which acts as a natural reservoir for the Mekong. Out of the lake comes the Tonle Sap river, which joins the Mekong at Phnom Penh. During the rainy season, the lake fills up, and during the dry season, the waters flow into the delta. The proposal is to put a dam with sluice gates on the lake, to provide greater control over the water flows than occurs naturally.

Once upstream control is provided on the Mekong, the next task is to build dykes for flood control along the river. Dykes are also needed all the way around the coast of the delta, to prevent sea water intrusion. This would provide for year-round irrigation.

The power generated by these dams would be very significant, approximately 20,000 megawatts, with 5,000 MW provided by the Pa Mong dam and 7,200 MW provided by the Stung Treng dam. Some of this power would be transferred to Thailand. Thailand would benefit from the entire plan, partly through irrigation of its northeast sector, a Mekong watershed area where tributaries are located.

Together with the mainstream development and the development of the delta, a series of projects would involve controlling the flow of the tributaries into the Mekong. When this was originally drawn up by the United Nations-sponored task forces, they considered both a short-range and a long-range plan: the first 10 years, from 1970 to 1980, were intended to be mainly tributary projects, with the large-scale projects coming on stream between 1980 and 2000.

The projects they outlined would increase food production from 12 million tons at that time to 37 million tons by the year 2000. Other experts consider such figures to be very conservative, reflecting a lower estimate of possible mechanization and fertilization of agriculture. But even as a baseline, such figures mean that the Mekong basin could once again become a breadbasket.

The total capital cost of this project, as estimated by the United Nations task force in 1970, was $12 billion. The total investment required was estimated at $30 to $40 billion over a 30-year period. Other experts have estimated higher investment costs, but the investment required for the projects would be remarkably small compared to the returns.

Gregory Buyhoff is a China specialist and Peter Ennis is an Asia specialist, both formerly on the staff of the Executive Intelligence Review. *Carlos Wesley heads the Central America desk of* EIR. *Dr. Steven Bardwell is editor-in-chief of* Fusion *magazine and director of plasma physics for the Fusion Energy Foundation. Charles B. Stevens is director of fusion engineering for the FEF.*

Water Management Key to India's Development

by Peter Ennis

The study prepared by the Fusion Energy Foundation in 1979, *India in the Year 2000: A 40-Year Program to Make India an Industrial Giant*, shows India's capacity to become a modern industrialized nation—if the latest, most advanced technologies are used. But the labor-intensive, and gradual, "organic growth" approaches advocated by the Club of Rome and the World Bank can only perpetuate economic backwardness. Nothing but a sharp, well-defined shock delivered to the entire economy, especially to the dominant but at best marginally productive rural and so-called unorganized sectors, will break the cycle of underdevelopment.

The key to Indian economic development is water management—the huge but unavoidable task of harnessing the subcontinent's immense water resources to break the deadly, centuries-old cycle of droughts and floods and create a modern agricultural industry to replace one of the world's least-productive rural economies. The irrigation and power reserves in India's river and hydroelectric balance are enormous, and an equally enormous effort is needed to develop them. To develop India's water resources would cost, according to the FEF study, $180 to $200 billion over a 30-year period, as the single largest industrial construction project for the entire subcontinent

This water development program would make India able to more than quadruple its electricity-generating capacity. At present, 8,000 megawatts, approximately 28 percent of India's total installed generating capacity of 28,000 megawatts, comes from hydroelectric power. The potential, even according to conservative estimates, is over 40,000 megawatts.

No region in the world is better suited for large-scale agricultural production than the Ganges-Brahmaputra river basin. While India today produces 120 million tons of grain per peak monsoon year, experts estimate that India could be producing over 1 billion, and perhaps 2 billion tons of grain per year! With the necessary fertilizer, mechanization and—most important—water, India could become a breadbasket for the world within 15 to 25 years. At present 43 million hectares are irrigated; the FEF plan would irrigate at least three times that area.

To manage its water resources, India must build a grid of canals linking the major river systems, to divert water from surplus to deficit areas and at the same time develop groundwater storage recharge and extraction sites. The FEF proposed a two-stage approach and timetable for the project, which incorporates some of the outlines for a National Water Grid first proposed by former Indian Irrigation Minister K. L. Rao.

The first stage of the program, 1984-2000, would construct a diversion canal from the Brahmaputra River, which carries a surplus of water, especially during the monsoon season, near Dhubri, to the Ganges River, near Patna. The canal would include outlets for irrigation releases to Bangladesh. A second diversion canal would be built from the upper Ganges and Yamuma Rivers in Haryana (north of Delhi) with groundwater recharge and extraction facilities en route to convey surplus water into the Sutlej Basin to the Western Desert through an enlarged Rajasthan Canal. Near Bikaner in western Rajasthan, a pump-lift canal facility would convey Himalayan water to the porous sandstone aquifers about 105 kilometers northeast of Jodhpur as a regulating storage facility. The dam, canal, and groundwater systems of each individual river basin will be developed in coordination with the anticipated facilities of the second stage.

Groundwater recharging and extraction systems must be improved. With the storage capacity of dams in the steep Himalayan river valleys limited, surplus runoff during the July-October monsoon season must be stored in groundwater systems, particularly in the Ganges Delta, where 65 percent of India's runoff flows.

The third priority is construction of flood control embankments and other means to improve the navigability of the lower Ganges and Brahmaputra Rivers. River training techniques developed by the U.S. Army Corps of Engineers on the lower Mississippi River would be effective. A competent master plan for Bangladesh, prepared by an engineering company in the United States in 1964, is being slowly, partially carried out by the Bangladesh government.

The FEF study proposed a crucial addition to this plan: a seawater barrier at the mouth of the Ganges, with saltwater-clearing navigation locks and sediment sluiceways similar to the Zuider Zee reclamation project in Holland. This feature is necessary to fully utilize the fresh water potential of the river system, especially during the low flow season.

Stage two, 2001 to 2015, would complete the groundwater recharge and extraction and the river diversion plans, and build the Ganges-Cauvery Link Canal. This canal, from Patna to the Cauvery River in the South, was originally proposed by former minister Rao, but the ultimate capacity of the canal proposed here would be 24 billion cubic meters per year, 10 times greater than the project he proposed.

The Ganges-Cauvery Link Canal will connect the major river basins of most of the states in the southern peninsula into a nationally regulated economic unit by providing inexpensive barge transportation for ores, grains, and bulk products from the south to the north. Of the total length of 1,640 miles, 440 miles will be in pump lift reaches of national rivers and 1,200 miles in gravity-flow canals or rivers.

The transcript of the Bangkok conference and the book, "A Fifty-Year Development Policy for the Indian-Pacific Oceans Basin," as well as copies of the 1979 study, "A 40-Year Plan to Make India an Industrial Superpower," are available. Address enquiries to Fusion Asia.

The World Economy Needs a Second Panama Canal

by Carlos Wesley

The Panama Canal, built by the United States in 1914 after 30 years of work by French and American engineers, has been rightly called "the eighth wonder of the world." Its construction linked the Orient with Europe and Africa, North America with the nations of western South America, and the Eastern Seaboard of the United States with the West Coast. Today some 14,000 ocean-going vessels pass through the canal each year, carrying over 160 million tons of cargo—more than 4 percent of total world trade.

While the Panama Canal is one of the greatest engineering achievements of mankind, its capacity even now is inadequate to modern shipping needs, and given any significant expansion in world trade the canal would soon become a major bottleneck. In the canal, a ship today must literally "climb" over mountains, by means of locks, as it is lifted from the Atlantic Ocean 85 feet above sea level, across the Continental Divide, and finally down to the Pacific Ocean. The canal locks and channels are too small to allow passage of some 8 percent of the world's ocean-going fleet, ships of over 65,000 tons (many bulk carriers and oil supertankers are over 250,000 tons). Furthermore, the locks are extremely vulnerable to sabotage or terrorism, and sinking one or more vessels in the lock-chambers could incapacitate the canal.

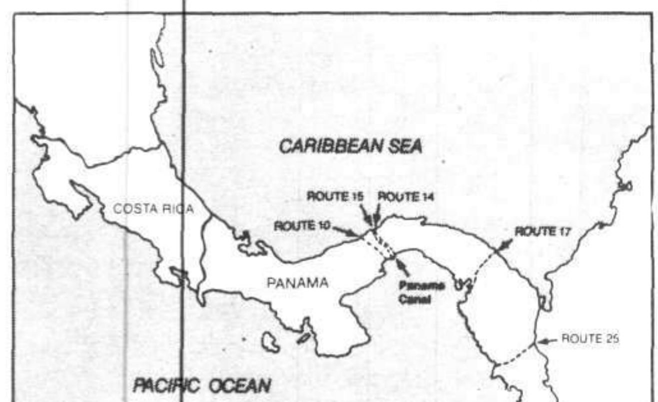
These considerations point to the urgent need for a new sea-level canal, as originally envisioned by the designers of the lock system. This will be one of the most monumental construction projects ever undertaken. Any canal across the isthmus that stretches from the Yucatan Peninsula in Mexico to northern Colombia will have to cross the mountains of the Continental Divide. Canal-builders will also have to contend with tropical forests and jungles before excavation can begin, and they will have to deal with the fact that sea level on the Pacific is usually slightly higher (about three-quarters of a foot) than on the Atlantic, and that there are marked differences between the tides of the two oceans.

Current estimates are that it will take anywhere from 8 to 20 years to get the job done—even if peaceful nuclear explosives (PNEs) are employed—and that it will cost $15 to $16 billion at today's prices.

The Atlantic-Pacific Interoceanic Canal Study Commission (ICSS), appointed by U.S. President Lyndon Johnson, in its 1970 report identified five routes across the isthmus, some suitable for building a canal by conventional means, and the others by a combination of conventional techniques and PNEs. Of these routes, Route 10, which is about 10 miles west of the existing Panama Canal, was selected as the best through which to build a canal by conventional means. Route 17, the Sasardi-Morti route through the jungles of Darien in Panama, and Route 25, the Atrato-Truando in Colombia, were identified as the best prospects for building a canal by combined techniques.

Although PNEs are significantly cheaper than conventional technologies, the fact that they cannot be employed near population centers limits their use to remote areas, offsetting their cost advantage. However, PNEs have the advantage that excavation and spoil disposal are accomplished in a single operation. According to the ICSS report, "energy produced in nuclear explosions would be used both to fracture material and eject it from the channel. This form of excavation would eliminate mechanical earthmoving, which is the major cost item in most conventional excavation. . . . Studies to date indicate that nuclear excavations may be several times less expensive than present methods in many applications and that effects can be satisfactorily predicted and controlled."

A Panamanian engineer, Demóstenes Vergara Stanziola, has recently proposed a nonnuclear construction design—"dredging the mountain"—to be applied on Route 10. This involves excavating, by conventional methods, two large artificial lakes, similar to the man-made Gatun lake that is the basis of the current lock canal. Large dredges and barge-lines would then proceed to dredge their way through the lakes, extending them until they are connected. This method would allow for efficient disposal of spoil from the excavation, with attendant cost savings. The finished canal would provide for simultaneous passage by two vessels of up to 250,000 tons, dispensing with the need for tidal-gates at each entrance.



Proposed Routes for a Second Panama Canal

Of the five routes proposed by the Atlantic-Pacific Interoceanic Canal Study Commission in 1970, Route 10 was selected as the best to build a canal by conventional means and Routes 17 and 25 as the best prospects for building a canal using conventional and PNE technologies.

Using Nuclear Energy For Construction

by Dr. Steven Bardwell and Charles B. Stevens

The development program for the Pacific and Indian Ocean basins intersects a global economic development process that is the advent of an industrial revolution at least as great as the industrial revolutions of the past. This is an industrial revolution based on new physical principles, high-intensity electromagnetic radiation, coherent forms of that radiation, and plasmas and their various technological spin-offs.

The fact that it coincides with the industrialization of the Pacific Basin gives that industrialization process a new unique advantage in the history of human economic progress. This process in the Pacific Basin does not need to replicate the stages of technological development that went on in the United States or Europe. Rather, that development can skip over a number of those stages and take advantage of the most modern, most efficient technologies, without having to go through the intermediate steps of different forms of more primitive industrial technology.

This is especially true of the large infrastructure projects proposed by the *Executive Intelligence Review* and the Fusion Energy Foundation. Here we describe the equivalent in terms of earth-moving technology of lasers for cutting metal or plasmas for refining metal—the construction equivalent of those new technologies.

If you look just in the most general sense at what characterizes present industrial technologies, they are all based on matter moving or shaping other matter. In the simplest sense, we have not moved much beyond the potter's wheel in terms of shaping metal. The lathe, the milling machine—all these are devices that turn matter and have other pieces of matter rub against the turning matter to cut it, shape it, to turn it into some useful form. The ideas on which the plasma and laser are based are *using energy to cut matter.* Matter never touches matter to turn it into a different shape; a beam of energy accomplishes that job.

In the area of construction technologies, the equivalent is the use of high-energy explosives to move earth, rather than a bulldozer or steam-shovel. This is using very highly organized, highly directed blasts of energy to move that earth.

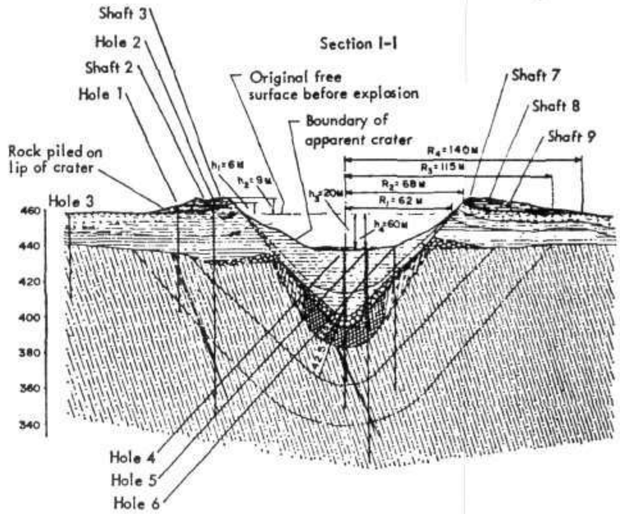
The basic idea is to bury, at a precisely determined depth, a small, precisely determined size of nuclear bomb. The depth and size depend on how big a hole you want, how much dirt you want to move, and what the soil and water conditions of the ground are. This device, because it is so intense, generates a very precisely calculable series of shock waves that do not merely blow things up, but in a very precise way, move earth from one place to the other. The idea then is not only to get dirt out of the way, but to use it as part of the construction material. The final form created is a crater, not just a hole, in which part of the ejected material forms a higher side of the crater; thus the result is not only a hole, but the sides of a hole that are desired, created by this precisely shaped explosive charge.

This idea is one that has a tremendous number of other applications in laser fusion, and other more exotic advanced industrial technologies—using focused pulsed power to create new forms of matter.

One of the few tests done that is in the open literature, a 50 kiloton blast 15 years ago, resulted in a very neat looking piece of work. In the middle of a desert at the Nevada test

Source: N. Seshagiri, *The Bomb!*, (New Delhi: Vikas Publishing House PVT, Ltd., 1975).

Three views of the Pokaran landscape in India's Rajasthan Desert, site of the May 18, 1974 PNE explosion. Top: Before the explosion; center: a new hill on the horizon seconds after the explosion; bottom: aerial view of the crater.



Cross-section of a typical peaceful nuclear explosion showing the crater and its geologic make-up. The blast in this Soviet experiment exceeded 100 kilotons (TNT equivalent explosive power) at a depth of 200 meters.

Source: Milo D. Nordyke, "A Review of Soviet Data on the Peaceful Uses of Nuclear Explosions," *Annals of Nuclear Energy*, Vol. 2, p. 657 (1975).

site, where weapons experiments are done, it looks from the air like a big ant-eater has been there. These blasts drill very precise conical holes with perfectly formed lips around them.

The application of this technology to moving massive amounts of earth has been much studied, and the economic impact of that technology is absolutely phenomenal. In all the studies done so far, it is uniformly shown that the cost of moving large amounts of earth can be decreased by a factor of four. That is, it costs about one-quarter as much to move earth using nuclear explosives as using bulldozers, and it takes about one-half the time. Most of the time it takes to do nuclear excavation is spent waiting for the right weather—in order to keep the blast from blowing in directions that it shouldn't. The time is spent waiting for what they call "blast days," days when one of these explosives can be set off and the results will be predictable.

The applications of peaceful nuclear explosives, besides earth-moving, include: extracting oil from oil shale; stimulating natural gas deposits; creating underground storage cavities for gas, oil or nuclear wastes; in situ mining of low-grade ore through nuclear rubblization and chemical leaching; stimulating the flow of oil fields; extracting ore from tar sands; deep seismic sounding to determine geological strata; deep coal and other mineral mining; extinguishing oil and gas-well fires; stimulating geothermal reserves; generating high-pressure steam for the production of electricity, fusion, and fission fuels; and stimulating underground water resources.

However, the main application currently discussed is for excavation of earth.

The only place this has been done on an industrial or commercial scale is the Soviet Union. A map taken from a Soviet publication shows a major water-diversion project, which is going to take one of the many water systems that runs from north to south in the Soviet Union and reverse that direction. A map was prepared by Lawrence Livermore National Laboratory and shows the sites at which known experiments using PNEs in the Soviet Union were done between 1965 and 1979. Most of these experiements were for the purpose of water diversion. In Siberia, the Soviets have been conducting a very extensive series of tests using PNEs to stimulate natural gas production. About 100 PNE experiments have been conducted there over the past 15 years for various purposes. This is a very real, economically viable technology in use in the Soviet Union, but not in use in the United States, purely for political reasons.

Prospects for the Pacific Basin

The original studies for both the second Panama Canal and the Kra canal, using PNEs, were done more than 10 years ago, and were based on the state of the art in PNEs at that time. In the intervening period, there have been tremendous advances, including vast reduction in the amount of radiation released. The amount of radiation released by a PNE can now be reduced by a factor of 100, which means that these explosives can be employed in relatively populated areas. If the size of the explosions can be reduced to the point that has been done in weapons tests today, this is in the ballpark of being able to construct in very precise ways, small craters or series of small craters.

The neutron bomb and the reduced-radiation weapon are weapons technologies that are also the key to the small, cheap, and clean nuclear explosives that will revolutionize construction technologies over the next 20 years.

What is most striking in the Panama Canal proposal is the spaced craters that are formed in the first phase of construction. After this first set of craters is formed, it would without doubt be one of the most remarkable feats of human engineering to watch the completion of that canal in the period of half an hour as the second series of explosions goes off. There would be a plume, the earth would subside, and then, out of nothing, a complete canal would be created—literally in half-an-hour's time.

Thailand is a nice country with friendly people and a temperate climate. Although it has internal political problems, economically it is on a strong footing—at least for the next few years. But in those friendly—almost idyllic—conditions, I saw something which I did not expect.

Thailand is a developing nation and will continue to remain so far a long time if they do not start thinking of their future now. The whole nation of 50 million people uses only 3000 MW or so of electricity. The country functions because it has plenty of food, a strong social fabric and a lot of smart people who do good business. But it lacks the most important ingredient that is necessary to become a developed nation: Thailand does not have an adequate number of scientists. It does not have an adequate number of technologists. But, it has a strong lobby of environmentalists. That is downright strange.

Usually in developing nations, one has to look hard to find an environmentalist. A few imports from Britain or Germany or the United States or somewhere else routinely hang around the college campuses looking for young ones with mental disorders to join their campaign against the "evils of progress." Most of these imports end up empty handed, with no supporter to fight for their cause. In such circumstances, common in most of the developing nations, these "imported" ones set up a foundation of some sort and try to make the anti-progress activities an institution.

But still the people do not join; only a handful of clever fellows seeking a foreign junket or two latch onto the foreign racket. Instead, the bulk of the people continue to complain that not enough construction projects are getting built, not enough power plants are being built, not enough factories are going up, and the country just isn't moving fast enough. Such a climate is unhealthy for environmentalists but, as we know, it is very healthy for the nation.

When I was in Bangkok, I expected there would be a few of these imports. That is a fair assumption to make since import of goods—consumer goods or otherwise—to Thailand is extremely easy. But I was in for a surprise. I found that the opposition to nuclear power comes not only from the "imported" ones, but also from a section of local academicians.

When I asked about it, my interlocutors whispered back into my ears: "We have no plans to build a nuclear power plant in the near future." They seemed scared of something.

Later I talked to many enlightened ones and found out that a few academicians based at Thammasat University in Bangkok and with questionable American friends are leading an "appropriate technology" movement in the country. Still, it was puzzling to me how these fellows could mobilise an anti-nuclear lobby when no move had been made to build a nuclear power plant.

I tried to think this through. One particular experience kept jarring my thoughts. It was a conversation I'd had with a scientist, a physicist in fact. I had cautiously referred to the prospective Thai nuclear power program, since one proponent had whistfully told me that maybe one plant would get built by 1995.

"We don't have nuclear physicists," my physicist jumped on the query. "If we buy it from outside, we won't be able to run it."

"Don't trust these people," he continued, referring I suppose to those long-suffering souls at the Office for Atomic Energy for Peace who have prepared several programmes and conducted training in nuclear technology. "They think it's like a car; you just buy it and run it. I don't think we can do it..." He paused, as if unconvinced by his own arguments.

I attempted to interject some perspective. "But if India can develop itself to handle nuclear power, surely Thailand can..."

He refused to consider it. "Nuclear is simply unreliable. We have never done it, so how could we now?" With that rhetorical flourish, the door slammed shut in his mind. Strange.

Finally I realised what the problem was. It's a case of the tail wagging the dog. It is not the environmentalist lobby that is to be credited for its own existence. On the contrary, it is the scientists' fear to confront these anti-progress elements. Even more important, it is their reluctance to speak out to make sure that the country implements those policies they know to be physically and economically necessary for advance that has given the anti-progress lobby its steam by default.

In this process the scientists are cultivating a deadly pessimism and lack of confidence among themselves that is already having a negative influence of policy. It is their own cowardice which has turned the scale in the opponents' favour and kept nuclear power development as far away from reality as it was in 1962.

Such, unfortunately, is the state of affairs in friendly Thailand. ■

GARUDA SPEAKS

The mythical bird Garuda expressed Man's earliest impulse to propel himself beyond natural barriers. Not simply Lord Vishnu's "flying machine," Garuda was also navigator and conscience, renowned for his keen eye.

The world will have widespread fusion power by the year 2000.

The only question is whether it will be delivered by an ICBM or a tokamak.

It's up to you!
With your help, the Fusion Energy Foundation can

- put *Fusion* magazine into the hands of 200,000 progrowth Americans
- educate America on the benefits—economic, military, and scientific—of developing directed energy beam technologies
- send speakers nationwide to debate nuclear freeze advocates on campuses and at community meetings
- promote science and technology—specifically the development of nuclear fusion and fission and space exploration—as the most important tools for continuing human progress.

Join the Fusion Energy Foundation and give gift subscriptions to *Fusion* magazine.

Oak Ridge National Laboratory

Yes I want to support the Fusion Energy Foundation.
Enclosed is:

☐ Sustaining membership $250
☐ Individual membership $75
☐ Corporate membership $1,000
(All memberships include 10 issues of *Fusion*)
☐ 1-year subscription to *Fusion* $20 (6 issues)
☐ 2-year subscription to *Fusion* $38 (12 issues)

Make checks payable to Fusion Energy Foundation, Box 1438, Radio City Station, New York, N.Y. 10101

Name ______
Address ______
City ______ State ______ Zip ______
Credit card ______ Card number ______ Expiration Date ______

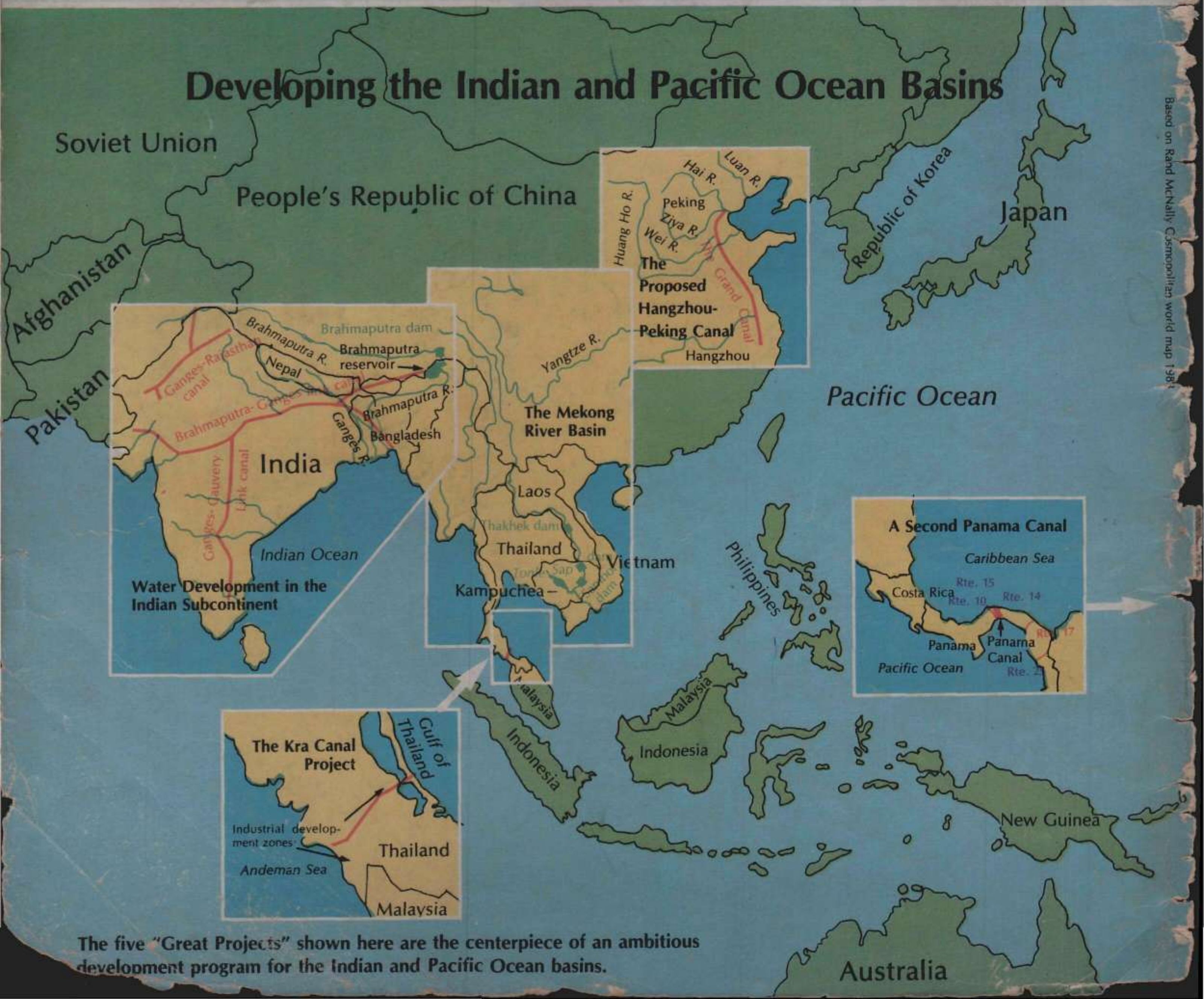
Contributions to the Fusion Energy Foundation are tax deductible. Visa, MasterCard, and Diners accepted.

GREAT PROJECTS: THE MOTOR FOR DEVELOPMENT

By the year 2000, close to two thirds of the world population will inhabit the countries on the Pacific and Indian Ocean rim. If the impressive growth rates some of the Asian nations have achieved during the past decade are to be maintained and enhanced, and the capacities developed to sustain this population at rising living standards, the Asian nations will have to take deliberate steps now to broaden, deepen, and hasten the process of industrialization throughout the region.

This is the unique aim of a "50-Year Development Policy for the Indian-Pacific Ocean Basins," a proposal based on a package of large-scale infrastructure projects that is featured in this issue. The intimate relationship between ambitious infrastructure development and successful economic growth is the key to the proposal. Spinoffs from such an approach include political stability, regional security, and a sure path out of world economic depression.

Australia, New Zealand	A$ 4.50
Bangladesh	Tk. 15
Burma	K. 7.50
China	U.S.$2.00
Hong Kong	HK$ 18
India	Rs. 7.50
Indonesia	Rp. 2500
Japan	Y. 800
Malaysia	M$ 6.90
Pakistan	Rs. 10
Philippines	P. 33
Republic of Korea	W. 2000
Singapore	S$ 6.50
Sri Lanka	Rs. 15
Taiwan	NT$ 100
Thailand	B. 65
U.S. and Europe	U.S.$ 5



The five "Great Projects" shown here are the centerpiece of an ambitious development program for the Indian and Pacific Ocean basins.