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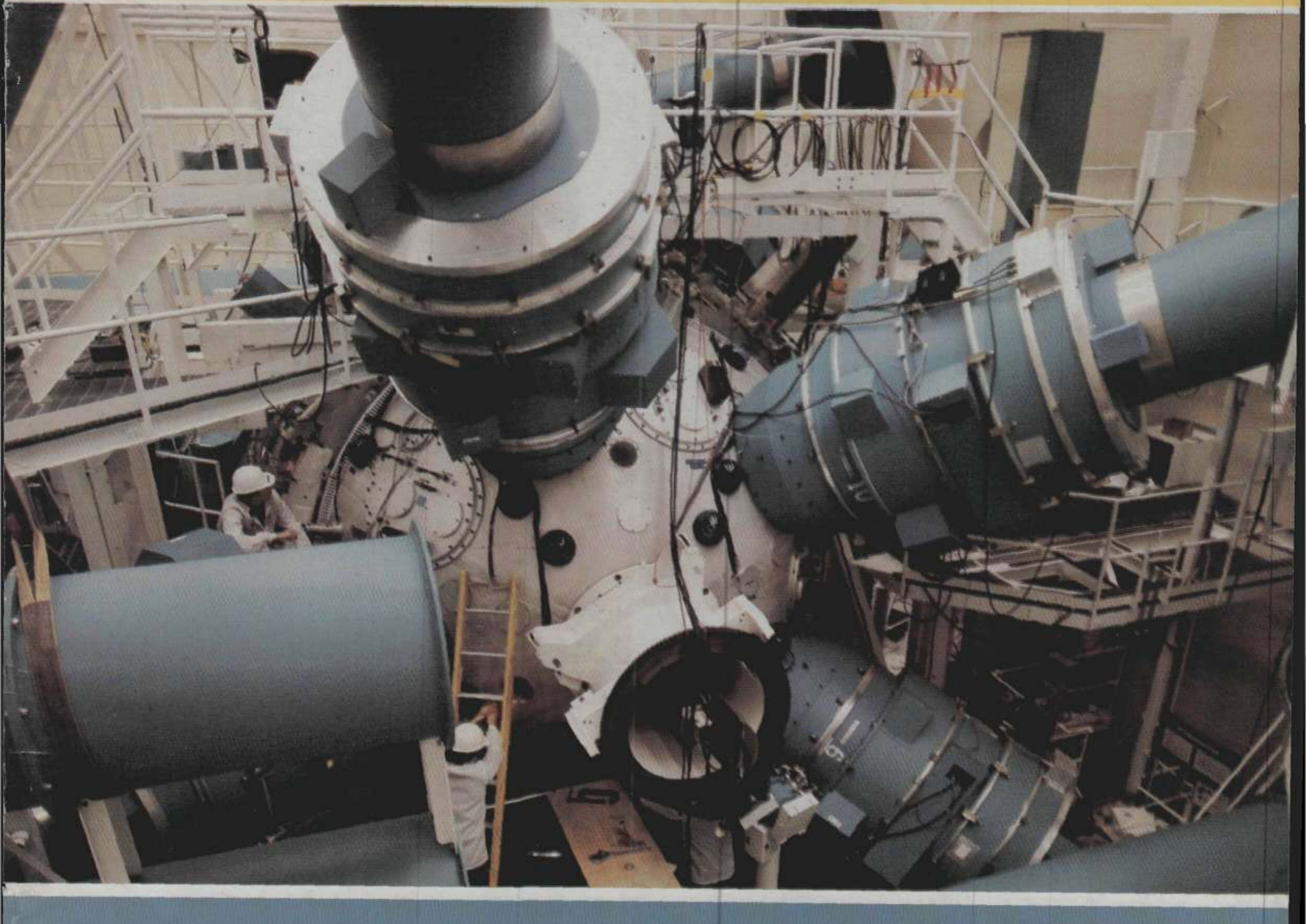

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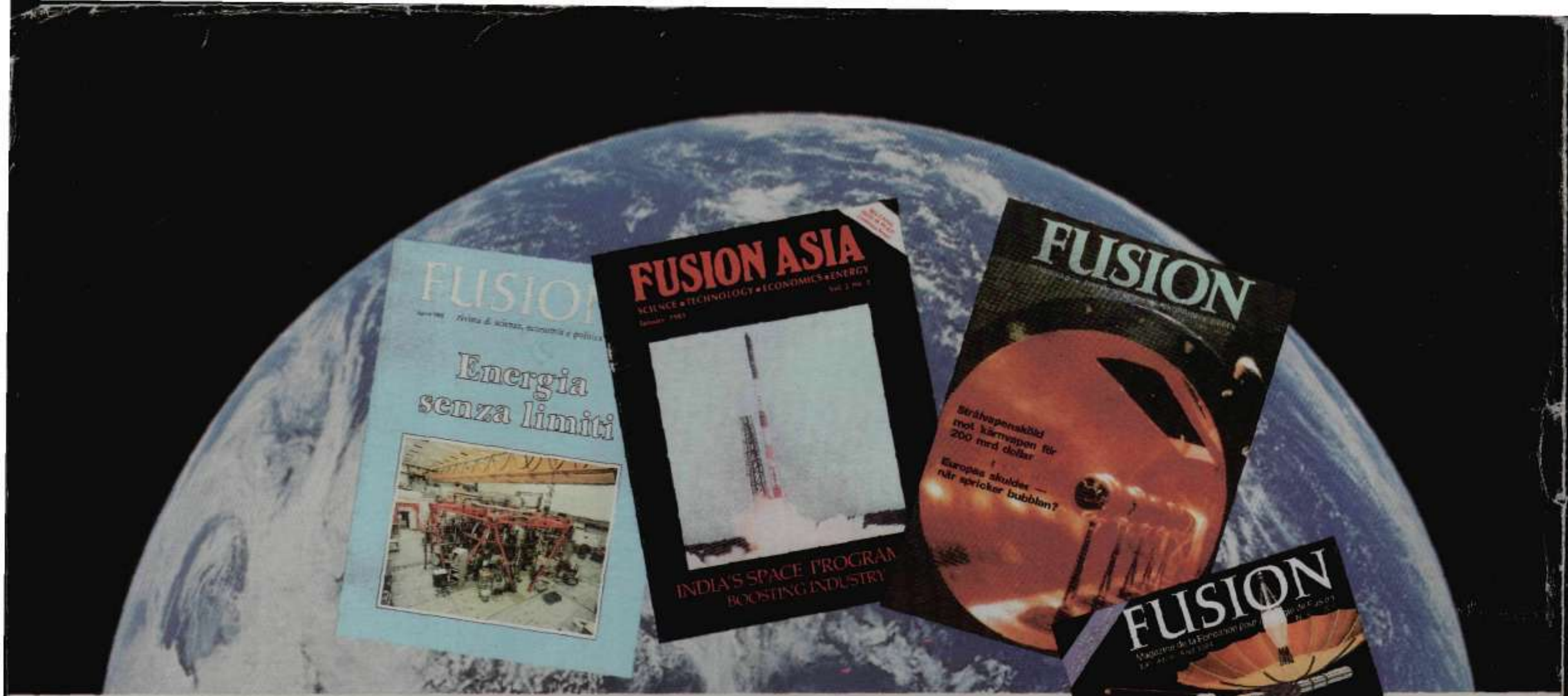

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Features

News

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On the cover: Laser technicians install diagnostic instruments on the target chamber of the Nova laser at Lawrence Livermore National Laboratory. Cover design by Virginia Baier; photograph courtesy of Lawrence Livermore National Laboratory.

Editorial

'The Key to Our Future

In the dog days of Gramm-Rudman, when the U.S. Congress blithely sacrifices the nation's industrial and defense capability to please the mythical goddess of the balanced budget, the words of President John F. Kennedy in May 1961, 25 years ago, could not be more appropriate:

> . . .If we are to win the battle that is going on around the world between freedom and tyranny, if we are to win the battle for men's minds, the dramatic achievements in space which occurred in recent weeks should have made clear to us all, as did the Sputnik in 1957, the impact of this adventure on the minds of men everywhere who are attempting to make a determination of which road they should take. . . .
>
> Now it is time to take longer strides—time for a great new American enterprise—time for this Nation to take a clearly leading role in space achievement which in many ways may hold the key to our future on Earth.
>
> I believe we possess all the resources and all the talents necessary. But the facts of the matter are that we have never made the national decisions or marshaled the national resources required. We have never specified long-range goals on an urgent time schedule, or managed our resources and our time so as to insure their fulfillment. . . .
>
> Recognizing the head start obtained by the Soviets . . . and recognizing the likelihood that they will exploit this lead for some time to come in still more impressive successes, we nevertheless are required to make new efforts on our own. For while we cannot guarantee that we shall one day be first, we can guarantee that any failure to make this effort will find us last. . . .
>
> But this is not merely a race. Space is open to us now; and our eagerness to share its meaning is not governed by the efforts of others. We go into space because whatever mankind must undertake, free men must fully share.

Kennedy had a sense of the importance of lifting men's sights up from the narrow corridors of Earthly business into the vast new frontiers of science out in space. In 1961, the United States not only rallied its best minds to meet the difficult goal of landing a man on the Moon before the end of the decade, but in the process educated hundreds of thousands of engineers and scientists. A climate of cultural optimism was created that permeated the society, infecting

on Earth'

every school child with the idea of progress, the idea that man could meet any scientific challenge—if he had the will.

Today, the potentials for using the most advanced science and technology as an engine to move the nation forward are even greater than they were 25 years ago. The next frontiers of space cry out for development—the manned space station, industrializing the Moon, colonizing Mars. These are difficult tasks that will require the best science and engineering we have, but all tasks well within our reach in the next 25 years, and tasks whose spinoffs will enrich society both materially and culturally by incalculable measure.

Breakthrough Within Grasp

There are other scientific frontiers as well, where breakthrough is within grasp. The unlimited, cheap, and clean energy of fusion power—using seawater as fuel—is closer today than ever before. The Fusion Report in this issue documents the fact that inertial confinement faces no insurmountable obstacles to achieving breakeven. As one fusion scientist from Lawrence Livermore National Laboratory told a Washington, D.C., meeting of the industry group Fusion Power Associates in April, there's no doubt that fusion is technologically possible. The problem is convincing those in power that the development of fusion is important, "otherwise, we're not going to get there."

How soon we break through the frontier areas in space and in fusion energy determines very simply the future course of the human race—how many human beings we will be able to support in the world at a standard of living equal to or better than the best U.S. standard today. But it is on the frontiers of biology and medical research, that this can be seen most starkly in life-and-death terms. It does not take very sophisticated mathematical skills to figure out how soon, at its current doubling rate, the killer AIDS will infect every single American. At the moment, AIDS is a 100 percent lethal disease that eventually kills everyone who is infected—unless scientists come up with a cure. This is an extraordinary challenge the nation cannot afford not to meet.

As President Kennedy put it in his famous speech on May 25, 1961, ."... I am asking the Congress and the country to accept a firm commitment to a new course of action—a course which will last for many years and carry very heavy costs." Today, we need a similar commitment at similarly heavy costs. If we do it, the returns to the economy will far outweigh the investment. If we don't do it, we will sacrifice the very survival of the human race.

Letters

The Next Generation: Advanced LWRs

To the Editor:

Subsequent to Marjorie Mazel Hecht's comprehensive and interesting article on "Mass Producing Nuclear Plants—The U.S. Can Do It," (*Fusion* March-April 1986, p. 51), I would like to provide further information here on the Advanced Light Water Reactor (ALWR) Program. This ALWR program, conducted by the Electric Power Research Institute (EPRI) in coordination with the Department of Energy (DOE), is the major U.S. effort in this area.

EPRI's Light Water Reactor development program has, for the first time, unified the utilities, plant vendors, and architect engineers into a comprehensive program to develop the next generation Light Water Reactors for the U.S. utilities.

The program has three major parts:

(1) Determine the set of stable regulatory requirements which must be met.

(2) Generate a utility and Nuclear Regulatory Commission (NRC) approved plant requirements document.

(3) Develop designs for a small (less than or equal to 600 MWe) Advanced PWR and a BWR.

Work on the first element of the EPRI program, stable regulatory requirements, has been underway for several years. Work to generate the utility plant requirements document was initiated in 1982.

In the development of a conceptual design for a small (less than or equal to 600 MWe) Advanced PWR, EPRI is responsible for the hardware and software development necessary to bring the designs to fruition and for NRC licensing certification.

Regulatory Requirements

Since the beginning of the program in 1982, more than 700 outstanding licensing issues were identified with NRC. So far, most of the issues have been resolved so that only 49 need to be treated in the Advanced Light Water Reactor requirement document. EPRI and NRC have jointly been working on screening criteria to evaluate new licensing issues which may surface during the ALWR design development period. These screening criteria will help to ensure regulatory stability by limiting new regulatory issues to only those which are important to safety. This process seems to be working well.

Utility Requirements Document

The purpose of the utility requirements document is to use utility operating experience with current nuclear plants to develop the design specifications for the next generation.

These requirements will be subjected to a widely based review to ensure that they reflect the utility needs and incorporate the latest available technology. This requirements document will be reviewed and approved by the Nuclear Regulatory Commission. The NRC will issue safety evaluation reports for the requirements document.

The new reactor design developed under this effort will be evolutionary rather than revolutionary in nature. Emphasis will be placed on proven design concepts. Designs which would require building a prototype reactor will not be considered. Importance will be placed on:

- elimination of unnecessary complexity
- enhancement of design margins affecting operations and maintenance
- evaluation of design conservatism
- improved constructibility, maintainability, and operability

In the area of plant simplification, a number of technical goals have been identified including:

- reductions in the number of valves
- standardization of valves
- elimination of pipe whip restraints
- simplified/highly reliable feedwater and condensate systems
- deletion of containment spray additive system
- simplification of the radioactive waste system
- automation of required tests and the number of technical specifications and associated performance inspections tests and limiting conditions of operations
- provision for a simple removal of steam generators and other major components

There is also an interest in evaluating the design margins to increase the operability and availability characteristics of the next generation light water reactor while reducing any excess conservatisms which may affect plant costs. Areas of design margins under consideration include:

- evaluation of lower power density cores
- enhanced natural circulation capability
- increased margins against small break loss-of-coolant accidents
- larger primary and secondary water inventories
- elimination of plant operating limits due to nil-ductility requirements
- extended plant design life over 60 years

In summary, substantial improvements over current design will result using this approach, without departing from proven technology. Based on the work to date, it is clear that this method is particularly valuable on a integrated, plant-wide basis.

Small LWR Development

Three contractor teams are now participating in the process of developing preliminary conceptual designs for small (less than or equal to 600 MWe) light water reactors. These include Westinghouse/Burns & Roe, GE/Bechtel/MIT, and Babcock & Wilcox/United Engineers & Constructors. Based on the preliminary results, two design teams will be chosen for the development of detailed designs. The Department of Energy has a parallel program of hardware and software development.

The Westinghouse/Burns & Roe project is developing two plant configurations in parallel. Concept A is an evolutionary improvement of the standard two-loop design. Concept B is a more advanced design with features developed for Defense Department reactors. Both concepts feature improved arrangement and modular constructibility.

Major features of the proposal include a 30 percent lower power den-

Continued on page 7

Viewpoint

The Tragedy of DDT

by Dr. Thomas H. Jukes

In 1962, the position of DDT as an insecticide seemed impregnable. It had eradicated malaria from many areas of the world, thus saving millions of lives and bringing health to hundreds of millions of people who would otherwise have been victims of "the monarch of diseases."

DDT had stopped massive epidemics of typhus fever and had helped to control many other arthropod-borne diseases such as plague and "river blindness" (onchocerciasis).

Whole populations had 10 percent DDT dust blown into their clothing as they wore it. The World Health Organization commented that "the only confirmed cases of injury have been the result of massive accidental or suicidal ingestion." Its effects on "nontarget species" occurred only in misuse, such as killing certain fish when sprayed on water.

The National Audubon Society, in 1961, had declared DDT harmless to birds when used at 1 pound per acre for control of the gypsy moth in Pennsylvania. Its usefulness in the global malaria eradication program continued despite the appearance of resistance. In 1962, Dr. R. Pal stated that the average life span in India was now 47 years compared with 32 years before the program, and that malaria in India had been reduced from 75 million cases to less than 1 million. Populations freed from malaria needed more food, and DDT played a second and major role in protecting crops to supply this.

Silent Spring and the Big Lie

The opening gun of the successful campaign against DDT was Rachel Carson's *Silent Spring*, in 1962. As a single example of its inaccuracy, the book stated that the American robin was on the verge of extinction. In 1963, however, Roger Tory Peterson said the robin was most likely the most numerous North American bird. Another outstanding piece of nonsense was the story that DDT in the oceans would kill all the algae and would bring an end to the world's supply of oxygen. This fear was echoed by the head of the United Nations, even though the original research showed no effect on algae by DDT at saturation levels in sea water.

Many of the alleged environmental ill effects of DDT probably resulted from PCBs or mercury, but this was ignored, and the campaign rolled on, aided by the mass media.

In June 1972, DDT became a victim of the big lie. It was banned in the United States for practically all uses by Environmental Protection Agency (EPA) administrator William Ruckelshaus. He declared in 1970 that DDT was safe and that "the carcinogenic claims concerning DDT are unproved speculation," but in 1972, he changed his tune. The Ruckelshaus ban overturned the recommendation of his examiner, Administrative Law Judge Edmund Sweeney, who had conducted nine months of public hearings on DDT for the EPA.

Judge Sweeney brought a fresh viewpoint without previous involvement with environmental or medical disputes. The record shows that he was fair. His impartiality infuriated the opponents of DDT, who apparently felt that he should favor them. When he admonished some of them for their poor evidentiary procedures, they became so enraged that they refused to appear the next day.

The opponents of DDT seemed to have a pipeline to *Science* magazine and to the *New York Times*, both of which attempted to prejudice the hearings by criticizing the judge, alleging that he lacked environmental expertise. So far as I know, neither publication sent a reporter to the hearings.

Appearing for the Montrose Chemical Company in defense of DDT were two vigorous and forceful attorneys, Robert Ackerly and Charles O'Connor. As they learned the facts about DDT, they became and remained strong supporters of its use. Indeed, Robert Ackerly has since written scholarly articles on DDT for *Chemical Times & Trends*, 1982. Their commitment gave unexpected pique to the hearings. During the cross-examination of DDT opponent Dr. George Woodwell, they elicited his admission that, in a study to show the DDT content of an area, he had taken soil samples where a DDT spray truck had been standing and he had reported these high values without correction.

Another tidbit came when Professor Joseph Hickey was reminded that he had stated in a 1942 publication that the number of peregrine falcons in the eastern United States had been declining since 1890, and in 1940 had dwindled to the precariously low level of not more than 140 mating pairs, long before the discovery of chlorinated hydrocarbon insecticides. Even today, mishaps to the eggs of peregrine falcons are blamed on DDT without an analytical test, and any mention of this picturesque bird is usually accompanied by remarks about the devastating effect (unsubstantiated, of course) of DDT on it.

More Lies

The question of DDT and cancer was also aired during the hearings. Cancer occurs in certain susceptible strains of mice fed DDT. There is no evidence linking cancer in human beings with prolonged and high levels of exposure to DDT, and former Surgeon General Jesse Steinfeld so testified in the hearings. Similar conclusions have been since reached by the National Institutes of Health.

One of the pro-DDT witnesses was Nobel laureate Dr. Norman Borlaug, who came to the defense because of his deep interest in prevention of hunger and disease in the developing countries. After the hearings, he was

Dr. Thomas H. Jukes is a Professor of Biophysics at the University of California at Berkeley.

called a paid liar by an official of the National Audubon Society as reported in the *New York Times* Aug. 14, 1972. Scientists Gordon Edwards, Bob White-Stevens, and myself were simultaneously so named.

We sued for libel, and won a jury verdict in U.S. District Court in 1976, only to have the decision reversed on appeal by Judge Irving Kaufman, who, according to the *Village Voice*, March 5, 1984, is a close friend of the *New York Times*.

In 1982, the Olin Corporation settled out of court for $24 million, against claims by residents of Triana, Ala., largely based on DDT residues in local fish. The main measurable effect was an increase in a blood enzyme, gamma glutamyl transpeptidase, and the U.S. Public Health Service said, "the effect is small and probably does not affect well being." As for the fish, they were being caught alive and well with DDT contents ranging up to 627,000 parts per billion, despite the stories told about DDT killing fish in *Silent Spring's* Chapter 9, "Rivers of Death."

A Town in Harmony

There was once a town in the heart of America where all life seemed in harmony with its surroundings.

The harmony of all life in this idyllic town followed a biological balance in Nature, a balance which man had not yet learned to disturb by drastic intervention on his own behalf.

As the Sun went down, the buzzing of mosquitoes could be heard in the town; the malaria parasites in their salivary glands were about to continue *their life cycle in the red blood cells of* human victims.

The last slanting rays of the Sun lingered on the small headstones in the town graveyards. Here slept the children who had perished from diphtheria, scarlet fever, and whooping cough. Beside them lay the bodies of those who had lived and died in harmony with proliferant typhoid germs.

These bacteria, uninjured by chlorine or antibiotics, teemed in the limpid stream that ran at the edge of town. It

flowed through meadows where grazed cows, beneath whose hairy flanks swarmed trillions of tuberculosis organisms, waiting for their milky ride that would take them to the lungs of the townspeople.

Life for these folks was a struggle with unrelenting Nature. Some of them, including the Carney family, had fled from Ireland at the time of the potato famine, when a fungus disease had turned the food supply to a stinking slime, so that many people had perished from starvation and from diseases resulting from starvation.

Famine had not laid its hand on the New World, but farmers knew what it meant to see a good field of wheat flattened by stem rust and the Hessian fly; a scabby and wormy apple crop lying on the ground; to see rows of young corn destroyed by cutworms and wire worms; pigs dead from hog cholera; and Canada thistles choking out the

The Olin Corporation stated, correctly, "we live in a time when the popular perceptions regarding a chemical are inconsistent with the scientific facts," and that to have pursued the matter in courts would have involved years of protracted trials and appeals. Such is the tragedy of DDT, which has been transformed from a savior of lives to a dangerous poison by means of the big lie.

Various reasons are possible for the impassioned virulence, the misrepresentations, and the distortions used against DDT. Entomologist Gordon Edwards suggests that DDT is resented for its major role in accelerating population growth. I have proposed that attacking DDT led to the greatest bonanza ever for environmentalist organizations. With financial success, they have used, and still use, the DDT issue to represent themselves as saviors of birds, people, and the entire biosphere from extinction at the hands of what they call the irresponsible and greedy "agribusiness complex." The most eloquent reason is given by Dr. Richard Rappolt, who said: "only DDT has the press and romance: only DDT was associated with a Nobel prize and success against typhus and malaria. . . . Reputations are made by killing heroes and, to some of the Lee Harvey Oswalds of the scientific world, DDT fulfills this imperial aura and 'when you strike at a king, you must kill him.'"

The best epitaph for DDT was written by Dr. Samuel Simmons in 1959 before the environmentalist attack started. He pointed out: "the total value of DDT to mankind is inestimable and is composed of health, economic, and social benefits. . . . Most of the peoples of the globe have received benefit from it, either directly by protection from infectious diseases and pestiferous insects, or indirectly by better nutrition, cleaner food, and increased disease resistance. . . . The discovery of DDT will always remain an historic event in the fields of public health and agriculture."

The defense of DDT was, from the beginning, a lost cause. A few of us vainly hoped that science would prevail. We soon found that Gresham's Law, which states that bad currency drives out good currency, applies to science as well as to economics.

I dedicate this brief essay to the memories of Bob White-Stevens, our tireless and silver-tongued humanitarian; Max Sobelman, manufacturer of DDT, who was dedicated to the fight against malaria and was an encyclopedic source of information; and George Claus, whose erudite and brilliant mind contributed so greatly to exposing fallacies by opponents of DDT.[1]

Note

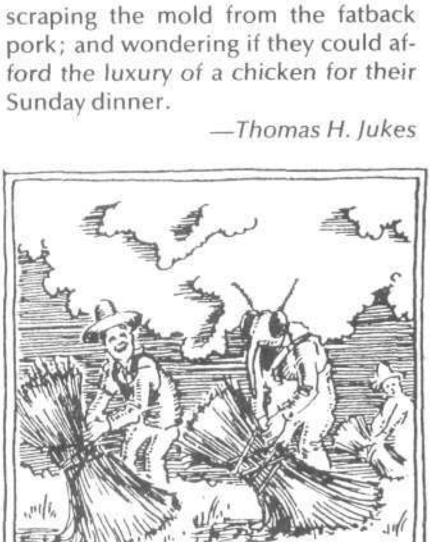
1. G. Claus and G. Bolander, *Ecological Sanity* (New York: David MacKay, 1977).

oats as the white, fluffy seeds sailed on the breeze to the next pasture.

It had been a warm afternoon, and a hush had settled on the grocery store. Faint sounds could be heard: a friendly rat gnawing in the cellar; the rustle of weevils in the cracker barrel; the high-pitched buzz of flies that were struggling in the sticky festoons hanging from the ceiling; and the stealthy patter of the cockroaches that darted across the floor.

Yes, life was in harmony with its surroundings. The women who, a century later, might have been writers of science fiction horror stories, were too busy with their housework to read humor magazines. They were squashing black beetles; beating the clothes moths out of the winter woolens; scraping the mold from the fatback pork; and wondering if they could afford the luxury of a chicken for their Sunday dinner.

—*Thomas H. Jukes*



Letters

Continued from page 4

sity core, a larger pressurizer and reactor vessel to provide increased primary water inventory, and stainless steel and water reflectors for the reactor vessel. Soluble boron is reduced by utilizing gray control rods, which also aid in the load following capability of this design.

The Concept B reactor coolant system has low flow resistance, eliminating the usual Westinghouse crossover leg. Canned motor pumps are being evaluated, as are passive safety systems, passive decay heat removal systems, and horizontal steam generators.

The main features of the GE/Bechtel/MIT design include natural circulation up to 600 MW; top entry control rod drives; an enlarged suppression pool that provides a three-day supply of water for decay heat removal in the event of loss of normal cooling water; a gravity-draining ECCS system; isolation condensers; elimination of safety grade diesels by utilizing a battery system, a passive three-day heating, ventilation, and air conditioning unit for the control room; simplified main steam reheat and feedwater heating design; and a construction time of 36 months.

The Babcock & Wilcox/United Engineering Contructors design is a two-loop plant with once-through steam generators with increased secondary coolant inventory and glandless reactor coolant pumps. Soluble boron is being reduced while the passive decay heat removal and other passive safety features are being upgraded.

Design concepts under development enhance the constructibility of the plant and field assembly of easily transported components. Modularity is also being developed.

As can be seen from the above discussion, completion of the EPRI program, as well as the complementary DOE and NRC efforts, will go a long way in providing realistic options for future ALWR orders by U.S. electric utilities.

Chaim Braun
Energy Study Center
Electric Power Research Institute
Palo Alto, Calif.

News Briefs

Above, President Kennedy speaking about the space frontier 25 years ago. Below, the cover of the 1986 report by the National Commission on Space, available from Bantam Books in paperback.

NATIONAL COMMISSION ON SPACE: RETURN TO THE MOON BY 2005!

Two days before the 25th anniversary of President Kennedy's May 25, 1961 challenge to land a man on the Moon by 1970, the National Commission on Space released its report, "Pioneering the Space Frontier," recommending that the United States plan to return to the Moon by the year 2005 and land men on Mars a decade later. Commission chairman Tom Paine, who was NASA administrator during the Apollo era, told a Washington press conference: "Stronger leadership and greater vision will be needed, but the expected benefits to America and the world will greatly outweigh the costs. Our report recognizes that the final decision will be made by the American people through its leaders in Washington. The Commission is therefore not prophesying, but describing what the United States can make happen through vigorous leadership in pioneering the space frontier."

THE SOVIETS ARE AHEAD, TELLER TELLS NEW YORK ACADEMY OF SCIENCES

"The Soviets have been working on this [strategic defense] system for at least 20 years," Edward Teller told a New York Academy of Sciences conference on high technology and war on May 8. "To assume that we are necessarily ahead is unjustified, and, in my opinion, completely wrong." Teller was countered by McGeorge Bundy, currently a professor at New York University and unofficially known as the head of the Eastern Establishment. "Fearing the Soviets obsessively is something we've done before and we should not do it in this case," Bundy said. Bundy stated that U.S. technology was ahead in many areas including computers, radar, propulsion, electrooptical systems, guidance systems, and software.

80 SCIENTISTS FORM GROUP TO SUPPORT THE SDI

Edward Teller, Frederick Seitz, Robert Jastrow, and Hans Mark are among the more than 80 scientists who formed the Science and Engineering Committee for a Secure World, to counter what they say has been a one-sided academic debate over the Strategic Defense Initiative. Spokesman Martin Hoffert, chairman of the Department of Applied Sciences at New York University, told a May 9 press conference, "There is considerable support for the SDI within the academic community . . . and a broad spectrum of scientists—of different political views." The group can be reached at (202) 547-5580, P.O. Box 76220, Washington, D.C. 20013-6220.

STRATEGIC DEFENSE: WHOSE SIDE IS THE APS ON?

Members of the American Physical Society (APS) who attended the annual spring meeting in Washington, D.C. April 28-May 1, were greeted at the Convention Center headquarters by a large banner proclaiming "Scientists Against SDI," and a table of literature on "Why Star Wars Is Dangerous" and how to lobby "Congresspersons" against the SDI. There were three major symposia on the SDI during the meeting, and none of them had invited representation from nongovernmental supporters of the SDI. The APS said no to a request by the Fusion Energy Foundation for a pro-SDI table and organizing room at the meeting.

AP/Worldwide Photos

Masked antinuclear terrorists throw rocks and bottles at police in Wackersdorf.

GREEN PARTY PUSHES FOR CIVIL WAR IN WEST GERMANY

Using the Chernobyl nuclear disaster as an excuse, the Soviet-funded Green Party and its terrorist offshoots staged a three-day riot in mid-May at the site of the Wackersdorf nuclear reprocessing plant in the state of Bavaria, West Germany, injuring 200 policemen. As the weekly *Der Spiegel* correctly characterized it, it was a "weekend of civil war," with thousands of Greens cutting through the plant fence, hijacking a passenger train and tearing up rail track, smashing power lines, and felling trees to block roads. When it became clear to the Bavarian police May 17 that the situation was out of hand, they requested help from neighboring states. Who supports this terrorism? The Social Democratic Party government of Saarland refused to send reinforcements to Wackersdorf, and when the West Berlin government attempted to send two water cannon, the East German border police stopped the cannon from leaving the city.

FEF TOKYO CONFERENCE GIVES JAPAN MANDATE TO JOIN SDI

"The SDI: Its Military, Economic, and Strategic Dimensions" was the title of a two-day Fusion Energy Foundation conference in Tokyo April 22-23 that drew 180 members of Japan's elite to discuss that nation's participation in the U.S. Strategic Defense Initiative. The consensus that emerged from the meeting was that Japan's participation as an equal partner in the SDI is necessary and urgent for Japan, both to counter a growing Soviet threat and as the impetus for a scientific and technological revolution. As Prof. Makoto Momoi of the Yomiuri Research Center put it, "Every day that Japan does not participate in the SDI is another day lost" in the battle to counter the Soviet threat. FEF research director Uwe Henke von Parpart told the group that Japan's full-scale participation in the U.S. Strategic Defense Initiative could shorten the research time for deployment by a full two years, while FEF European director Jonathan Tennenbaum documented how SDI technologies will create a 100-fold leap in energy flux density, abruptly reversing the decline in productivity in industry. Other conference participants include Col. Molloy Vaughn (U.S.-ret.), Gen. Revault D'Allonnes (France-ret.), Ozeki Tetsuya of the Japan Research Institute, Nobuki Kawashima of the Aeronautics Institute of Tokyo University, Prof. Sakata of Tokai University, and fusion scientist Fred Winterberg of the University of Nevada's Desert Research Institute.

Stuart K. Lewis

Nobuki Kawashima addressing a 1985 FEF Conference on the SDI.

FEF HOLDS ROME CONFERENCE ON ITALY'S SCIENTIFIC TRADITION

"From Leonardo da Vinci to hypersonic flight: Italy's contribution to economics and defense" was the theme of an April 29 conference in Rome that drew 100 participants, including many of the military and scientific network that experimented with supersonic flight and hydrodyamic vortices at the Guidonia aerodynamic center near Rome 40 years ago. The conference was cosponsored by the FEF and the Schiller Institute, and organized on the basis that Italy's participation in the U.S. Strategic Defense Initiative will only be fruitful if Italy's classical scientific tradition is revived. Among the speakers were Prof. Bernardino Lattanzi, one of the first researchers at the Guidonia school in the 1930s; Giuseppe Filipponi, director of the FEF in Italy; FEF executive director Paul Gallagher, who discussed the SDI; German-language *Fusion* editor Heinz Horeis, who had just returned from the SDI conference in Japan; and Dino de Paoli, who spoke on Leonardo da Vinci and the networks of Bernhard Riemann in Italy.

LOUSEWORT LAURELS TO PHIL DONAHUE

This issue's Lousewort Laurels award goes to television talk show host Phil Donahue for his recent, well-publicized tantrum. When Donahue walked past the table selling *Fusion* magazine at LaGuardia airport in New York May 11, he yelled at organizer Bill Ferguson, "You're a Nazi." Ferguson, who is black, replied "You should be in prison," at which point the antinuclear Donahue put down his bags and lunged at Ferguson. The resulting tussle made national headlines, especially given the heightened interest in nuclear issues after the Chernobyl disaster. Donahue and his actress wife Marlo Thomas were on their way to Boston where she was to accept a peace award from antinuclear activist Helen Caldicott. "The fact that Phil Donahue may get away with slandering people on television, does not mean that he has a license to physically assault people at will," said Ferguson, who has filed a complaint against Donahue.

United Kingdom Atomic Energy Commission

If all the electric power used by one man during his lifetime were generated by nuclear power alone, the amount of radioactive waste that would be produced would fit in a piece of glass this size.

Nuclear Waste: Don't Bury It, Recyle It As Fuel

by Marjorie Mazel Hecht

What we call nuclear "waste" is actually a valuable resource. More than 96 percent of the so-called waste produced by nuclear reactors can be reprocessed to be reused as uranium or plutonium fuel; only about 4 percent is actually high-level radioactive waste that requires disposal. And even this high-level waste could be transformed into a resource: Advanced isotope separation technologies could separate and concentrate it into its constituent isotopes—including costly and scarce strategic metals like rhodium, ruthenium, and palladium.

By treating as "waste" all of the spent fuel produced by a single 1,000-megawatt nuclear plant over its 40-year lifetime, the United States throws away the equivalent of 130 million barrels of oil or 37 million tons of coal. This does not even take into account the value of the strategic metals and other isotopes that could be "mined" from the high-level waste.

During the Atoms for Peace years, one of the selling points for nuclear power was its closed fuel cycle, because it was clear that this would cheapen the use of nuclear power and ensure a steady supply of fuel no matter what became of the natural uranium supply. The other nations that went nuclear—Canada, France, England, Japan, and the Soviet Union, for example—completed the nuclear cycle and are reprocessing their fuel. What happened here?

The answer has little to do with the technology involved; it is a political question. From the beginning of the nuclear age, scientists and the government were convinced that the disposal of high-level nuclear waste was technologically feasible and safe.

Thirty years ago, in 1957, the National Academy of Sciences recommended that high-level waste could best be disposed of by burial in geological salt formations. In a report to the Atomic Energy Commission, the NAS committee stated that it was convinced that "radioactive waste can be disposed of safely in a variety of ways and at a large number of sites in the United States." They advised the immediate investigation of a "large number of potential future sites as well as the complementary laboratory investigations of disposal methods" so that the nation would be prepared to handle the waste expected from an increasing number of civilian reactors.

This was then accepted as U.S. policy, with the general assumption that the United States would develop commercial reprocessing facilities and that only the high level waste remaining after reprocessing would require permanent disposal. The Oak Ridge National Laboratory in Tennessee conducted further studies, and by 1969, Oak Ridge had developed a design for a repository for high-level waste in deep salt deposits.

A site was selected in Lyons, Kansas, to test the suitability of salt burial in 1971, after an advisory committee appointed by the President concluded that "the establishment and burial of high-level waste can be carried out safely." The Lyons site was abandoned in 1972 as inappropriate, however, when the AEC discovered that salt mining was still going on a few miles away. The Atomic Energy Commission then began to develop an interim plan for a Retrievable Surface Storage Facility, which it expected to begin receiving waste for storage in 1980.

This concept was overturned in 1975, however, when the successor agency to the Atomic Energy Commission, the Energy Research and Development Agency or ERDA, decided once again to pursue a site for a salt repository and investigate other geological possibilities for repositories. ERDA's aim was to have an operational salt repository by 1985.

ERDA abandoned the idea of interim repositories not because of any technical difficulties, but under pressure from the environmentalists and the Environmental Protection Agency, which charged that the repositories would become "permanent dumping grounds."

Then Came Jimmy Carter

Then came the Carter administration. President Carter banned the reprocessing of spent fuel in 1977 on the basis of nonproliferation; reprocessing facilities, the administration said, would make plutonium accessible to terrorists who could then convert it to a weapons-grade fuel.

Carter guaranteed that the waste issue would remain a political football. By then the antinuclear movement was off and running, with the President on their side. In looking at what Carter did, it is hard to avoid the conclusion that his administration hoped the antinuclear movement would be able to use the waste issue to bury civilian nuclear power in the United States.

At the same time that Carter chose to make burial of nuclear waste the only option for the United States by eliminating reprocessing, he also bogged down the plans to build a repository for high-level waste by creating a new interagency bureaucracy (the Interagency Review Group on Nuclear Waste Management).

The political battle today over where the waste repositories should be located is the legacy of that bureaucracy and the antinuclear obstructions it encouraged.

Under the provisions of the Nuclear Waste Policy Act, signed into law in 1983, the Department of Energy has tentatively named three sites (narrowed down from nine) for the nation's first repository and is awaiting a final environmental assessment from the National Academy of Sciences on these sites (Hanford, Washington; Yucca Mountain, Nevada, and Deaf Smith County, Texas). After further evaluation (which includes the construction of exploration shafts 1,000-4,000 feet deep to determine rock conditions), the President will select the final site in 1991.

The schedule is then to have the Nuclear Regulatory Commission issue a construction permit in 1993, and to have spent fuel and high-level waste begin to come into the first repository by 1998.

The site selection for a second repository is also mandated, this one to be located in the Eastern or Midwestern United States. Twelve potential sites were recently announced, which set off the environmentalist howls. This list is expected to be narrowed down to five by 1989, and then three sites will be presented to the President in 1993 for him to choose. A final decision is scheduled for 1999, with the construction permit obtained in 2002. The recommended budget for both depositories is $769,349,000.

All of these sites are being extensively researched by the national laboratories and other contractors for the Department of Energy for geological considerations. In addition, there has been ongoing research on the most efficient way to prepare and store such waste.

The only way to understand why a project for burying nuclear waste that was deemed both feasible and safe in 1957 is still on the drawing boards in 1986 is to look at the decline of cultural optimism in the United States and the necessarily parallel growth of the environmentalist movement.

The opponents of nuclear power and the industrial growth that it symbolizes understood very well that their enemy was "technological optimism." The Office of Technology Assessment consultant on the waste management issue, Daniel Metlay, wrote the follow-

What Is High-Level Nuclear Waste?

The spent fuel from a nuclear plant is removed after about three years in the fuel assembly, when the concentration of the fissile uranium-235 in the fuel is less than about 1 percent and the chain reaction is impeded. A 1,000-megawatt nuclear plant would replace about 60 of its fuel assemblies per year.

The spent fuel includes uranium and plutonium (if not reprocessed), all the fission products that have built up in three years or so of operation, and very small amounts of some transuranic elements (heavier than uranium)—neptunium, americium, and curium, among others—which have very long decay times.

Initially, the spent fuel is very hot, generating about 221 megacuries of radioactivity and 2.2 megawatts of thermal heat per metric ton. The spent fuel is stored in water pools to cool it and to provide radiation shielding. After one year in the water, both the radioactivity and the heat output decline by factors of 88 and 216, respectively. In other words, after a year or so, the total radioactivity level is about 12 percent of what it was when it first came out of the reactor, and after five years, it is down to just 5 percent.

How long do these most hazardous isotopes live? Unlike other poisons like lead or arsenic, radioactive isotopes become harmless with time. This decay process is measured in terms of "half-life," which refers to the amount of time it takes for half of the mass to decay. While a few radioisotopes have half-lives on the order of thousands of years, the hazardous components of nuclear waste rapidly decay to a radioactive toxicity level lower than that of natural uranium ore. To take the example given by the Electric Power Research Institute, "the strontium in waste becomes less toxic than natural uranium ore in 450 years. The total waste, including plutonium, becomes less toxic in 500-1,000 years, depending on the fuel history. . . ."

Note that if the waste is not reprocessed, it takes 10,000 years for the toxicity to fall below that of natural uranium.

Radioisotopes As Resources

Separating out some of the nearly 500 radioactive isotopes from high-level nuclear waste not only creates a valuable new resource for medicine and industry; it also vastly lessens the toxicity of the remaining waste. In effect, removing the radioactive isotopes from high-level nuclear waste is like "aging" the waste—the radioactivity is decreased. For example, if cesium-137 and strontium-90 are removed, the effect will be that of aging the waste hundreds of years. If the platinum group metals are also removed—neptunium, americium, and technetium, for example—this has the effect of aging the waste thousands more years.

Many of these radioisotopes are already in use. There are now between 80 and 100 million medical procedures yearly, for example, that use nuclear isotopes. In addition, the Department of Energy has an extensive plan for recovering and using these nuclear by-products for defense as well as civilian purposes.

- Plutonium-238 is now used to power heart pacemakers, as well as small reactors in space.
- Cesium-137 is used as the radiation source in food irradiation plants and is experimentally being used to process sludge—turning sewage into a pure and usable fertilizer product.
- Strontium-90-powered radioisotope-fueled thermoelectric generators (RTGs) have been used to provide electric power for remote weather stations as well as remote surveillance stations, navigational aids, and defense communications systems. A strontium-90 thermomechanical generator is now being developed for use with low-power radar systems and remote emergency power sources.
- Krypton-85, tritium, and promethium-147 are used in self-powered lights. When the first spacecraft docked, it was promethium-147-powered lights that guided the final maneuvering. These lights use beta-emitting radioisotopes to activate phosphors, and are particularly appropriate for remote or tactical applications. The promethium-147 is especially promising because it requires considerably less shielding than the krypton-85.

Nonradioactive krypton is also used in fluorescent and incandescent lights, where it is superior to nitrogen or argon. Since natural krypton gas is scarce, it could be profitably "mined" from the fission product krypton.

- The platinum group metals—including platinum, palladium, rhodium, iridium, ruthenium, and osmium—are costly imports for the United States, which uses about 35 percent of the yearly world production and imports nearly 90 percent of this. (South Africa produces 46 percent and the Soviet Union 48 percent of the world supply.) Advanced isotope separation processes will be necessary to develop these resources to maximum advantage.

These metals have a high melting point, chemical inertness, catalytic properties, and refractoriness, according to the Department of Energy plan for nuclear by-product use. They are now used in industry as catalysts and inhibitors of corrosion, in electronics, and in medical applications. As the National Research Council noted, the platinum metals are "generally either the only material that can be used or the most cost effective of the available options, and therefore, replacement seems unlikely to be significant. Indeed, the usage trend seems likely to accelerate more rapidly over the forecast period than at any other time in history."

ing about the Atomic Energy Commission in the March 1985 OTA report on waste:

"An illusion of certainty was created where, in reality, none existed. Over the years, the sense of technological optimism embedded itself in the attitudes and thoughts of important agency policymakers. It became, in a sense, an official doctrine at AEC. There is no evidence that its validity was ever seriously questioned until the mid-1970s. . . ."

The Reprocessing Story

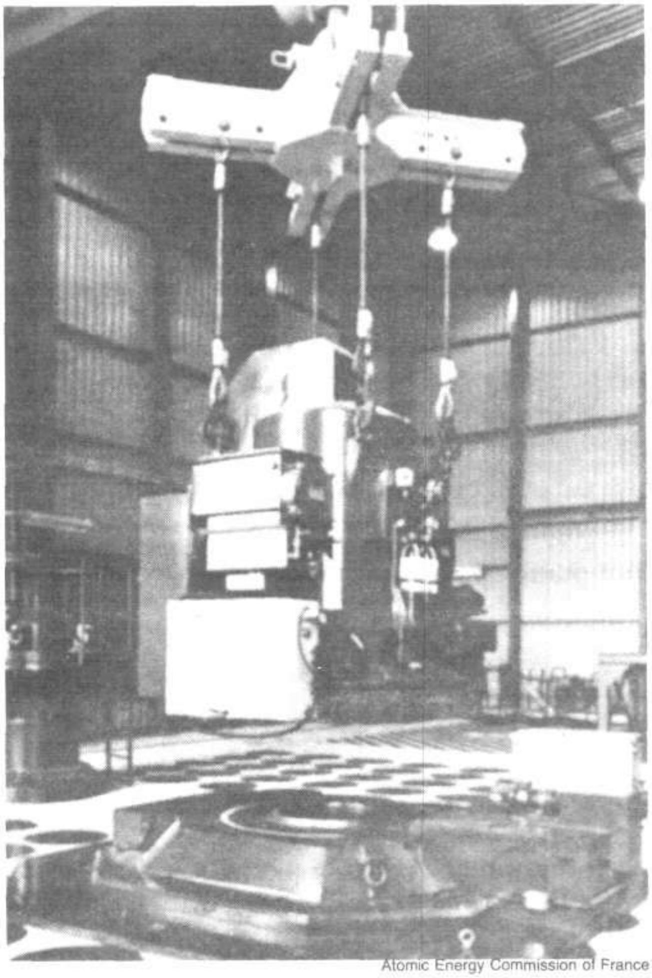
In the early days of the nuclear age, that there would be a commercial reprocessing industry was taken for granted by the cutural optimists. Thus, the permanent burial of waste was not seen as urgent, and the research proceeded to test geological formations over a period of years.

But commercial reprocessing—a 40-year-old technology—was aborted in the United States, despite its advantages both in reducing the amount of waste that has to be disposed of and in rendering the high-level waste in a less soluble, hence safer, form.

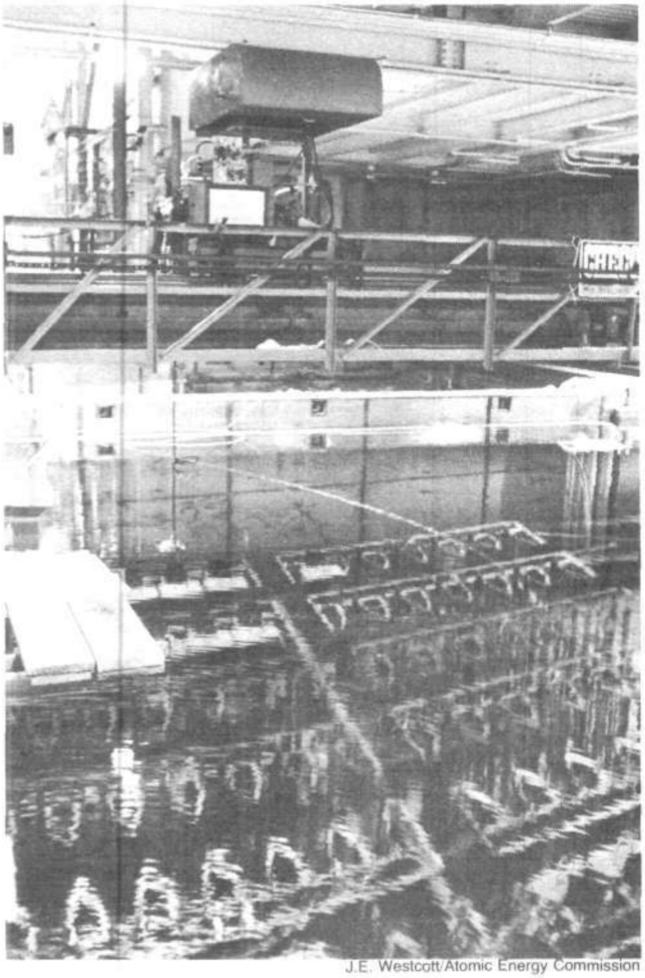
Although France began commercial reprocessing in 1958, the first U.S. commercial reprocessing facility did not open until the late 1960s. The West Valley, N.Y. plant, operated by Nuclear Fuel Services, was reprocessing commercial spent fuel from 1966 to 1972. The plant was in the process of modernizing and expanding to handle a larger volume of waste, when the environmentalists intervened to delay the Nuclear Regulatory Commission's licensing of the expansion. Finally, in 1976, the private owner gave up entirely because it had become too costly to maintain an unused plant.

Another reprocessing facility in Morris, Ill., built by General Electric in the early 1970s, never opened because an unanticipated design flaw caused by new regulatory requirements necessitated changes in the plant that GE deemed too costly to make.

A third facility at Barnwell, N.C., operated by Allied General Nuclear Services, is the one that President Carter stopped in 1977—when it was 75 percent completed—with his ban on reprocessing. At the same time, Carter's actions halted the plans of the Exxon



Atomic Energy Commission of France



J.E. Westcott/Atomic Energy Commission

France has pioneered in nuclear waste storage. At left, France's AVM vitrification plant at Marcoule, where steel canisters of radioactive waste are stored dry in air-cooled wells under ground. Right, unlike the other major nuclear nations, the United States now has no commercial reprocessing of nuclear waste. Here, General Electric's reprocessing plant at Morris, Ill., which never opened. Shown are the water-cooled basins where spent fuel is stored pending reprocessing or burial.

Nuclear Co. to build a commercial reprocessing plant in Oak Ridge, Tenn., which was planned to be larger than the other three plants.

The Reagan administration could have rescued the Barnwell plant in 1981, but as with the Clinch River breeder reactor, Reagan chose to abandon this technology to a "private enterprise" system so sunk in the depression that it could not pick up on these major infrastructure development projects. Reagan also reversed Carter's policy of providing federal facilities for utilities to store spent fuel, and again made this the responsibility of individual utilities.

How Much Waste?

The closed West Valley reprocessing plant has about 234 metric tons of high-level waste from its reprocessing of spent fuel, and both the Morris and Barnwell facilities have storage pools for spent fuel. Other spent fuel is stored, at the nuclear plants where it was generated, in water-filled basins to dissipate the heat and allow the decay of the short-lived fission products. By the end of 1983, there was an estimated 4,600 cubic meters of spent fuel being stored at plant sites, with about 620 cubic meters additionally expected each year.

There is no problem in continuing to store spent fuel in these pools for 30 to 35 years, but according to Department of Energy estimates, the interim storage room available at plant sites will be full by the end of the 1980s.

In addition to the commercial spent fuel, there is also a much larger volume of high-level waste from the defense program, 324,000 cubic meters. This waste is stored at government facilities in Hanford, Wash., Savannah River in South Carolina, and in Idaho. The defense waste has all been reprocessed at the two government-operated reprocessing facilities.

Although the commercial spent fuel is only about 1 percent of the volume of defense waste, it has a higher level of radioactivity and heat output because the defense waste is diluted. The Department of Energy estimate is that defense waste has a radioactivity of 1,370 megacuries, while the commer-

cial waste has a radioactivity of 35,700 megacuries. (One curie is the quantity of radioactive isotope that decays at the same rate as 1 gram of radium, 3.7×10^{10} disintegrations per second.)

To get an idea of the relatively small physical dimensions of the problem: All the high-level waste from U.S. commercial nuclear plants would fit into one 1.5 square mile underground repository.

The Technology of Disposal

There is no mystery to the permanent burial of nuclear waste. The basic method used today in France was actually developed in the 1950s by Brookhaven National Laboratory, and there has been a steady stream of improvements in the technology to make the waste more stable.

The liquid waste is mixed with glass frit, and then poured into a 1-inch thick stainless steel canister that is 10 feet high and ½ to 2 feet in diameter. The canister is heated until the glass melts and then it is cooled, which fixes each atom of the waste solidly in the borosilicate glass. The canister is then packed in another barrier of molded steel, and the entire assembly is surrounded with a metal or ceramic corrosion barrier. Finally, the assembly is buried in a specially designed vault in a geological formation in salt, volcanic rock, or granite, which forms an additional barrier. The United States has been testing various geological formations to see which are the most stable for long term storage.

The general principle is to set up a system of multiple barriers, to ensure that no radioactivity is released.

The tests that the French have done on this vitrified waste indicate that after 900 years of storage time, the glass will still be a satisfactory storage medium. According to the International Atomic Energy Agency, such glass is so stable that even if placed in flowing warm water, "it would take 100 years to dissolve away about 1 millimeter of the surface of such a glass."

There have also been advances in the preparation and transportation of fuel. For example, the casks for transporting waste are probably the best designed containers ever made. They became famous in films made by the Sandia National Laboratories showing trucks with waste casks colliding full speed with a locomotive or crashing into a wooden structure. In all these dramatic tests, the cask emerged unscathed.

Alternative methods of waste disposal have been developed that are also ready now. For example, fluidized bed calcining, developed at the Idaho Chemical Processing Plant near Idaho Falls, solidifies the waste and stores it dry. The defense waste at the Idaho facility has been stored in this manner.

The Future

The pioneers of the atomic age saw the Atoms for Peace program as a way to lift mankind out of poverty worldwide and into an age of plenty. Their technological optimism is as right today as it was in the 1950s. We should be mass producing nuclear plants for domestic use and export and we should overturn the present "throwaway" nuclear fuel cycle and implement a reprocessing program. If we immediately gear up to reprocess nuclear waste and turn 96 percent of it—and probably all of it—into new resources, there would be no problem of nuclear waste burial.

Fusion Power Associates

Stephen O. Dean, President

December 20, 1985

Freedom of Information Appeals Officer
Office of Science and Technology Policy
The White House
Washington, D. C. 20500

Dear Sir:

This is an appeal pursuant to subsection (a) (6) of the Freedom of Information Act, as amended (5 U.S.C. 552).

On December 1, 1985, I sent your agency a letter (copy enclosed) requesting a copy of the interim report of the National Research Council's panel to review the inertial confinement fusion program. That report was submitted to your agency several months ago. My request was submitted under the terms of the Freedom of Information Act. I have received no response.

As you know, the FOIA provides that an agency must make an initial determination of whether to comply with an FOIA request within ten working days of receiving the request. Since I have allowed more than a reasonable time for compliance, I am treating your agency's failure to respond as a denial. This letter is a formal appeal of that denial.

As provided for in the amended Act, I will expect to receive a reply to this appeal within twenty working days.

Sincerely,

Stephen O. Dean

Enclosure

2 Professional Drive, Suite 248 • Gaithersburg, Maryland 20879 • (301) 258-0545

Target chamber of the Omega laser at the University of Rochester's Laboratory for Laser Energetics, one of the three civilian laser facilities.

LLE

EXECUTIVE OFFICE OF THE PRESIDENT
OFFICE OF SCIENCE AND TECHNOLOGY POLICY
WASHINGTON, D.C. 20506

February 10, 1986

Dear Mr. Dean:

Please accept our apology and excuse the inordinate delay in responding to your request of December 1, 1985 under the Freedom of Information Act and your appeal of December 20, 1985. The delay and apparent denial of your request was caused primarily by the resignation and departure of Dr. Keyworth as the Director of the Office of Science and Technology Policy. With a very small staff, this change did cause some delays in the administrative areas.

At the present time we are denying release of the interim report of the National Research Council's panel to review the DOE's inertial confinement fusion program because the report contains information which requires coordination with other agencies.

We will notify you as soon as we receive the results of the coordination and of our decision concerning release at that time.

Best regards,

Jerry D. Jennings
Executive Director

Mr. Stephen O. Dean
Fusion Power Associates
2 Professional Drive, Suite 248
Gaithersburg, Maryland 20879

EXECUTIVE OFFICE OF THE PRESIDENT
OFFICE OF SCIENCE AND TECHNOLOGY POLICY
WASHINGTON, D.C. 20506

March 17, 1986

Dear Mr. Dean:

As indicated in our letter of February 10, 1986, in response to your Freedom of Information Act request, we denied release of the interim report of the National Research Council's panel to review the DOE's inertial confinement fusion program pending required coordination with other agencies.

This review has been completed with the determination that the report may be released, and therefore, a copy is enclosed herewith.

Best regards,

Barbara J. Diering
Special Assistant to the Executive Director

Enclosure

Mr. Stephen O. Dean
Fusion Power Associates
2 Professional Drive, Suite 248
Gaithersburg, Maryland 20879

LASER FUSION BREAKTHROUGH IMMINENT

The Report The White House Tried to Suppress

In late 1984, angered by the administration's moves to curtail the civilian laser fusion program, the House Armed Services Committee wrote into the fiscal 1986 Appropriations Act a stipulation requiring the Executive Branch to carry out a full review of the inertial confinement fusion program. Because of the program's obvious military importance, the House committee wanted an accurate assessment of where the program stood.

The Executive Branch called on the White House Office of Science and Technology Policy to conduct the review, which in turn chartered the National Academy of Sciences to carry it out, and the National Academy then appointed a distinguished panel of scientists to do the job. From March through May 1985, the review committee visited the various inertial confinement fusion laboratories and reviewed the literature, including the progress of laser fusion abroad. On July 15, 1985, the National Academy's Committee for Review of the Department of Energy's Inertial Confinement Program submitted an interim report to White House science advisor George A. Keyworth. (The report appears in full in the accompanying article, p. 18.)

Like the previous government-mandated review of inertial confinement during 1979-1981, this report was highly optimistic. In fact, Professor William Happer, Jr. of Princeton University, the chairman of the review committee, noted "that the outlook for inertial confinement is today more optimistic than at the time of the last major review." The program has made "striking progress over the past few years," Happer said, and we know of "no physical reason" why the goal of the program cannot be achieved.

After reviewing the particular successes of the program and the implications for civilian energy and nuclear weapons, the report also notes that "steady, rational funding of the program is essential for the next few years" and makes several recommendations for how to proceed, including how to deal with the issue of classification.

Buried at the White House

The response of the White House was not to hold a press conference and announce the good news, but to sit on the report for eight months, refusing to release it to Congress or to the public. Why would the White House Office of Science and Technology Policy bury such a report?

The obvious reason seems to be that the report's evaluation and recommendations contradicted the stated administration policy of putting the inertial confinement program under military wraps. In fact, the administration's budget request for fiscal year 1987 proposed reducing the inertial confinement fusion budget to a mere $23.8 million, a de facto phase-out of the civilian laser fusion program. The administration claimed that this reduced budget was only for the non-DOE labs working on laser fusion—the Naval Research Laboratory, the University of Rochester's Laboratory for Laser Energetics, and KMS Fusion—and that the national weapons laboratories would be funded through the undisclosed military budget.

In the previous budget, the administration had proposed a cutback from $168 million in 1985 to $70 million, but the House Armed Services Committee and subsequently the full Congress voted to restore the budget to a level of $155 million.

So, the report sat in the deep-freeze for several months. On Dec. 1, 1985, when no word of the report had been released, Stephen O. Dean, president of the industry group Fusion Power Associates, wrote a letter to George A. Keyworth, then presidential science adviser, to request a copy of the report under the Freedom of Information Act. Dean is a former head of the Department of Energy's Magnetic Confinement Program and a veteran of fusion budget battles.

Fusion scientist Stephen Dean

"It is important for the civilian program to have an identity of its own. If you know how much is spent on the program, then you can evaluate its progress. It should not be subsumed into a largely unidentified weapons program."

Three weeks later, after Dean had received no reply, he wrote a second letter citing the law, which also received no response. In addition, the White House initially refused to let Happer, the chairman of the committee that prepared the report, testify before the Senate Armed Services Committee on the progress of the inertial confinement program. Finally, under threat of subpoena, Happer was allowed to testify Feb. 19, 1986.

By that time, the suppressed good news had turned into a public flap in the science community, and a month later, the full report was sent to Dean.

Budget Fight Ahead

The House Armed Services Committee is expected to oppose the Department of Energy's plan to abolish the civilian laser fusion program, and congressional hearings are taking place this spring. According to Dean, whose Fusion Power Associates group represents the fusion industry, the contractors are pushing for a separate civilian laser fusion budget line, and so are the national laboratories.

"It's important to note," Dean said, "that the inertial confinement program funded within the military program at the Department of Energy is recognized by the Academy of Sciences to have great potential for civilian applications. Therefore we need an open program, with as little classification as possible, and we need to widely distribute the news of this program to the public."

Dean also stressed that it is important for the civilian program to "have an identity of its own. If you know how much is spent on the program, then you can evaluate its progress. It should not be subsumed into a largely unidentified weapons program."

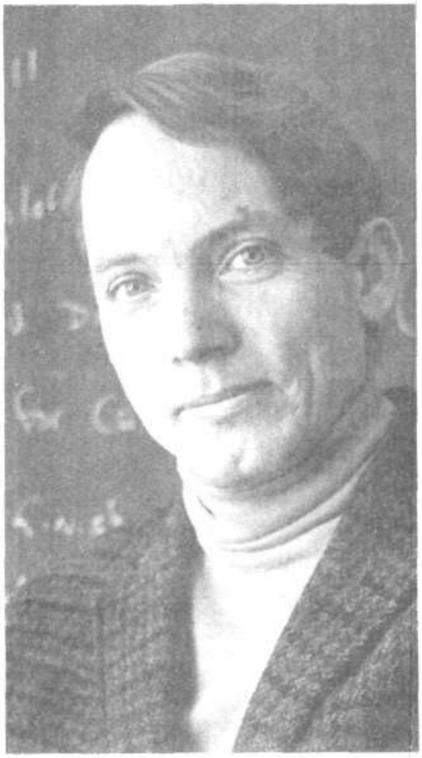
Dean said that DOE's two administrators of the military laser fusion program, General Withers, DOE assistant secretary for national security, and Admiral Foley, director of the DOE Office of Military Applications, simply "don't want to bother managing a separate civilian program. They don't want to spend the time and effort."

The management of the civilian part of the program could be kept within the DOE's Office of Inertial Fusion or put under the DOE energy research division, but the weapons people don't want to do that, Dean said. "They would rather abolish the DOE civilian effort altogether."

'Striking Progress'

Despite the efforts of the administration to bury inertial confinement in potters field, the actual successes of the research program would convince any reasonable, concerned citizen that the program should be fully funded so that it can reach breakeven as soon as possible. Here are some excerpts from the testimony of Professor Happer, chairman of the National Academy's review committee, to the House Armed Services Committee Feb. 19, 1986:

"As you know, the goal of the Inertial Confinement Fusion (ICF) Program



Review committee chairman William Happer, Jr.

"The ICF Program is today a vigorous and successful research effort which has made striking progress over the past five years, and . . . the outlook for success is more optimistic today than at the time of the last review."

is to produce a propagating thermonuclear burn in a small laboratory pellet imploded by a pulsed laser or particle beam. . . . We know of no physical reason why that goal cannot be achieved. Certainly we were persuaded that the ICF Program is today a vigorous and successful research effort which has made striking progress over the past five years, and that the outlook for success is more optimistic today than at the time of the last review. . . .

"The Committee was very favorably impressed by the quality of research facilities and the work being carried out. It was particularly impressed by the caliber and the motivation of the research teams assembled at each of the research centers. These teams are a national resource not easily or quickly reassembled once they are disbanded. . . .

"If the decision point referenced earlier is to be reached in a timely fashion, steady, rational funding over the next few years is essential. The ICF Program has traditionally been identified as a line item in the DOE budget. The majority of the Committee feels that this program identity should be maintained. There are serious problems with including the ICF Program in the RDT&E portion of the DOE weapons program. Separate line-item funding of the ICF Program would facilitate the support of the smaller groups at the Naval Research Laboratory, the University of Rochester, and KMS Fusion.

Finally, it would make the spotting of failures, as well as successes, of the program easier with priorities adjusted accordingly. To help DOE evaluate, and guide the program through the next five years, we recommended the establishment of a continuous oversight committee."

'Too Optimistic'

Happer concluded: "Mr. Chairman, that completes my formal testimony, but I would like to include a final comment. The only consistent external criticism of our interim report has been that it is too optimistic and that our credibility will suffer because of it. Since we do not wish to waste the efforts of a group of very busy and very dedicated committee members, nor the work of scores of people who supported our review, we redoubled our effort to find technical, operational, and managerial flaws in the program. Our final report will not be without criticism. However, that redoubled effort produced nothing that would alter my testimony here today."

Other members of the National Academy of Sciences review committee were John Dawson, UCLA; Harold Agnew, former head of Los Alamos National Laboratory; John Foster, TRW, Inc.; George Carrier, Harvard University; Conrad Longmire, Mission Research Corp.; Robert F. Christy, CalTech; Charles McDonald, R&D Associates; Ronald C. Davidson, MIT; and Marshall N. Rosenbluth, University of Texas.

—Marjorie Mazel Hecht

INTERIM REPORT OF
THE NATIONAL ACADEMY OF SCIENCES

Inertial Confinement Fusion Makes 'Striking Progress'

We reprint here in full the interim report submitted July 15, 1985 to Dr. George A. Keyworth, Science Adviser to the President, by William Happer, chairman of the Inertial Confinement Review Committee of the National Academy of Sciences' National Research Council. As described in the accompanying article, p. 15, the report was not released to the public until March 17, 1986.

* * *

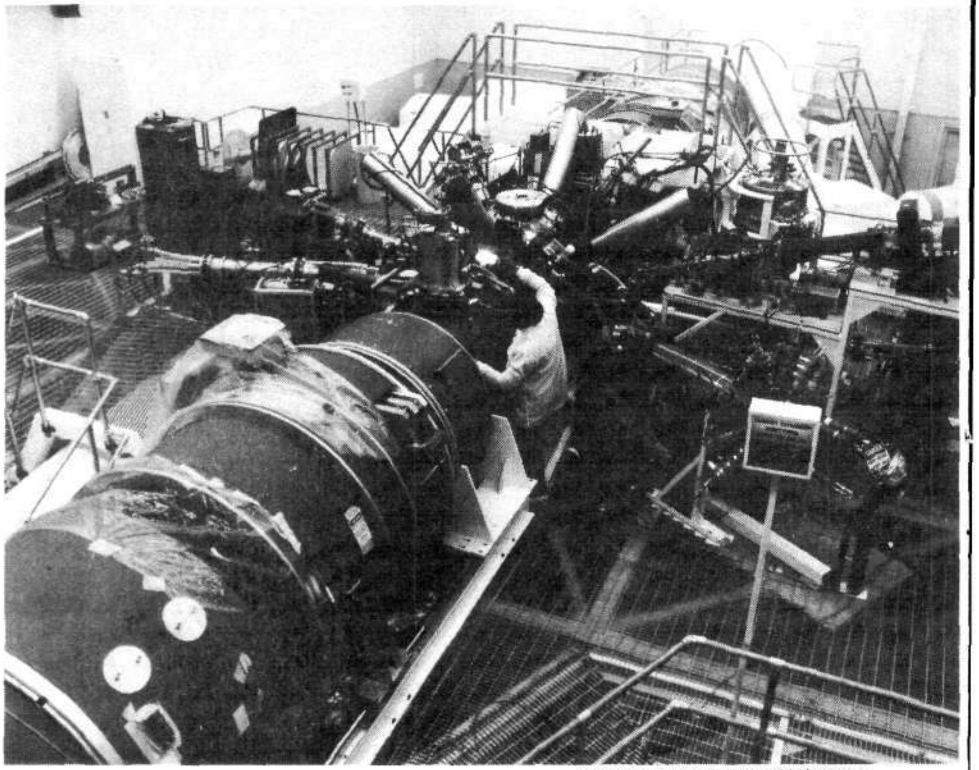
The charge to the Committee for a Review of the Department of Energy's Inertial Confinement Program [ICF] may be paraphrased as follows: (a) review all major areas of the Defense Inertial Confinement Fusion Program with emphasis on accomplishments, management, goals, and anticipated contributions; and (b) indicate the priority of the major activities within the present and future ICF program along with an appropriate time scale for achieving the program goals. The charge also indicated the desirability of an interim report by June 1985. In this and later responses to the charge the Committee wishes to make it clear that it has considered the ICF program only and makes no judgment regarding its relative importance within the overall research and development program supported by the Department of Energy.

The Committee has now completed an overall review of the ICF Program (March 4-5, 1985), and site visits to the Naval Research Laboratory (March 6, 1985), University of Rochester (April 20, 1985), KMS Fusion (May 3, 1985), Sandia National Laboratory (May 12-13, 1985), Los Alamos National Laboratory (May 14-15, 1985), and Lawrence Livermore National Laboratory (May 30-31, 1985). In addition, the committee has reviewed much of what is known of the ICF research outside the United States. However, much work remains to be done before we can confidently set forth our findings in a final report due in early 1986. Therefore, the contents of this initial report should be viewed solely as interim impressions gained from the wealth of information provided us thus far, and the inspection of laboratories, equipment, and auxiliary facilities at each of the sites previously noted. However, we hope the impressions set forth in this interim report will prove of some value to the decision process operating between now and the time of the final report.

Based on its work to date, the Committee is convinced that the ICF Program is a vigorous and successful research effort which has made striking progress over the past few years. Discussions with those who participated in previous reviews clearly indicate that the outlook for ICF is today more optimistic than at the time of the last major review (1979-1981). This increased optimism is due, primarily, to the encouraging results of short-wavelength laser-pellet interactions; to the impressive new information beginning to flow from the Halite-Centurion program; to the near completion of two major new facilities—that is, the PEBFA II light-ion accelerator at Sandia National Laboratory and the Nova laser at Lawrence Livermore National Laboratory; and to continued development and application of sophisticated computational codes.

Program Applications

The goal of the ICF Program is to produce a propagating thermonuclear burn in a small laboratory pellet im-



Lawrence Livermore National Laboratory

At right, target chamber of the two-beam Novette laser at Lawrence Livermore National Laboratory, which in 1984 produced the shortest wavelength soft X-rays ever observed in a laboratory—155 angstroms. In addition to beam defense applications, X-ray lasers promise a revolution in medicine and biology, providing 3-dimensional moving pictures of living matter on the atomic scale.

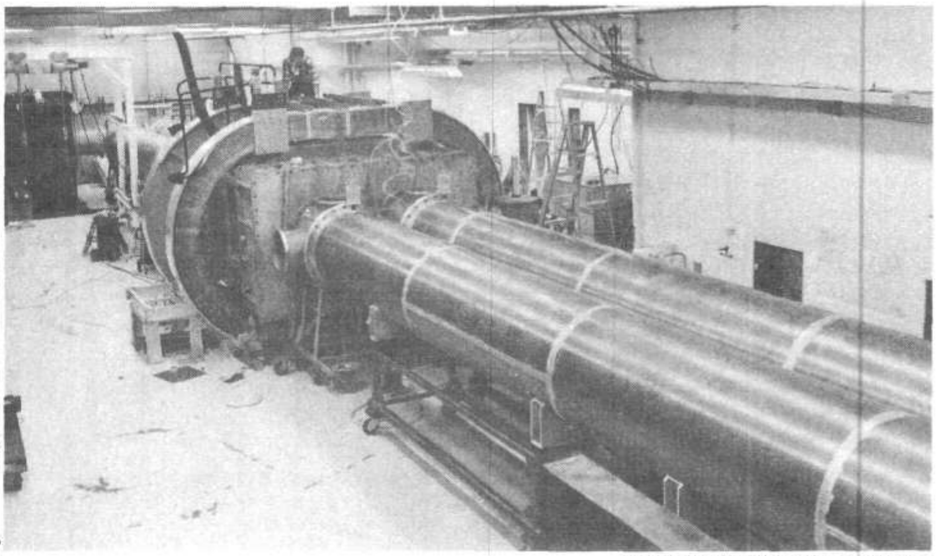
ploded by a pulsed laser or particle beam. The most immediate application may be to the weapons technology base. A miniature thermonuclear explosion in the laboratory with a yield of, say, 1,000 megajoules (¼ ton of high explosive) would supplement the technology-base information now gained from expensive and cumbersome underground tests, and in much shorter time. While a single laboratory experiment might be able to expose only one tenth as many reentry vehicles or other objects as an underground test, still, with rapid turnaround, relative ease of experimentation flexibility, and so forth, there can be little doubt that a successful ICF facility would benefit the nuclear weapons program by a reduction in costs of the effects testing now done, and by the introduction of experiments now thought unjustifiable by virtue of cost.

The Committee further notes that expensive test instrumentation now lost in each underground test could be largely recovered following ICF microexplosions in the laboratory. And, although underground tests have unique value for many purposes, other important scientific and technical issues might be addressed as well or better with ICF microexplosions. Some meaningful examples are: (a) the effects of intense short-duration neutron and X-ray bursts on various devices; (b) the physics of target implosions; (c) the effects of hydrodynamic instabilities and of various target or driver asymmetries; (d) the performance of novel multilayer target designs; (e) the generation of EMP; (f) the use of explosion products to make lasers, microwave generators, and other directed energy devices; (g) the measurement of radiation opacities under unusual conditions of temperature and chemical composition; and (h) testing the validity of sophisticated weapon design codes.

From a longer-range viewpoint, of course, the demonstration of an ICF microexplosion in the laboratory could be a useful tool in the development of ICF as a source of commercial electrical power.

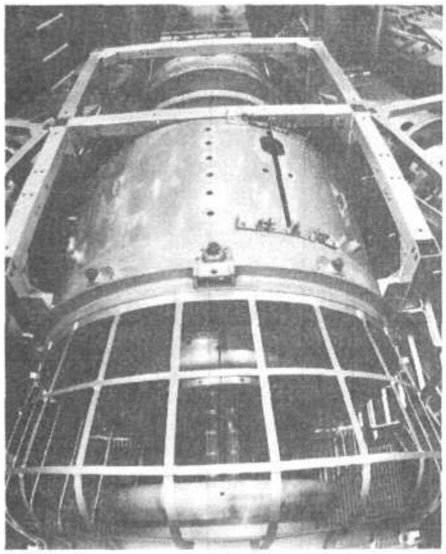
It is quite likely that the results of the Nova, PEBFA-II and Halite-Centurion programs over the next 3 to 4 years will indicate whether a laboratory microexplosion can be achieved as well as the required size of the driver. Assuming a positive result from these campaigns, it will still require a sustained effort of about 10 more years before it will be possible to ignite a pellet with a laboratory driver. And, early in that time frame, it is quite likely that an intermediate-scale driver will have to be constructed in order to prove the technology of the full-scale driver. Current estimates indicate that a full-scale laser driver would require about 10 megajoules of directed energy per pulse compared to the present energy level of about 50 kilojoules.

The largest elements of the ICF program are being carried out at Sandia National Laboratories, Los Alamos National Laboratory, and Lawrence Livermore National Laboratory. The Halite-Centurion program is jointly managed by Los Alamos and Livermore. Smaller, but very vital parts of the program, are being carried out at the Naval Research Laboratory, at the University of Rochester, and at KMS Fusion. The Committee considers these smaller efforts to be very important to the overall health of the ICF Program and to the progress it has thus far made. This is especially true during this intermediate stage where research is being directed toward the most cost-effective way to build a driver large enough to ignite a thermonuclear burn. In-



Fred Rick/Los Alamos National Laboratory

The krypton fluoride gas laser Aurora at Los Alamos National Laboratory achieved a record output of 10,500 joules within 500 billionths of a second—a power of about 20 billion watts. Because of its efficiency and high repetition rates, it is a prime candidate both for fusion and beam defense. Shown in the foreground is a section of pipe through which electrons pass. The electrons energize the krypton-fluoride gas located in the containers between the two large magnets that are used to confine the electron flow.



Sandia National Laboratories

Fusion scientists at Sandia successfully test fired the particle beam fusion accelerator Dec. 11, 1985, seven weeks ahead of schedule, and expect to demonstrate significant inertial confinement gain before the end of 1988. Shown here is one of 36 accelerators in the PBFA-II.

deed, the most active work on direct drive is going on at the Naval Research Laboratory and at the University of Rochester.

These smaller programs have provided important new ideas, insights, and experimental methods, which have been profitably used by the larger laboratories. The University of Rochester serves the vital function of identifying, attracting, and training young researchers, and making them available to the overall research program. The smaller laboratories also provide highly competent, knowledgeable, and constructive criticism of the larger programs; criticism which is especially valuable since it comes from active research participants, not from equally well-intentioned but less well-informed outsiders. Finally, the small laboratories as well as the larger facilities have served to attract and maintain teams of highly qualified and experienced scientists and engineers; a national resource of considerable importance. Through interaction and transfer, the weapons program has already benefited greatly from this resource.

Important Achievements

There have been many important technological achievements made by the ICF Program, notably the development of extremely high energy glass and CO_2 lasers, and the development of extremely intense particle beams. The program has stimulated the creation of a completely new commercial manufacturing capability for large optical components capable of handling very high optical powers. The large CO_2 laser (Antares) at Los Alamos has proven to be an unusually intense, pulsed source of hot electrons, microwaves, and X-rays. The Novette glass lasers at Livermore have been used to drive the first laboratory X-ray laser. Remarkable developments in materials science have resulted from the demands of target designers; for example, the development of new machinery and welding methods for very small, fragile targets. Significant advances in pulsed power technology have been made; for example, the ability efficiently to add the power from many magnetically insulated vacuum transmission lines with excellent time synchronization. Remarkable new instruments for diagnosing imploding pellets have been developed; for example, ultrahigh-resolution X-ray pinhole cameras. It seems certain that these instruments will find important applications elsewhere. The existing knowledge of laser-plasma interactions has been largely created by the ICF Program, and a rich variety of phenomena has been revealed and quantitatively understood.

The ICF Program requires expensive facilities such as laser and particle-beam drivers, target fabrication facilities, the Halite-Centurion support facilities, and major computational support. While these facilities are probably adequate for the current needs of the program, it is clear that lasers and perhaps particle-beam drivers must be scaled up significantly in energy to attain the ultimate goal of pellet ignition. Drivers require many years to construct. The design of a new generation of drivers should logically depend on the scientific results obtained with the current generation of drivers in order that the most effective design choices can be made. However, this serial approach to the program will result in very slow progress toward pellet ignition. With the shutdown of the Antares laser there will be no laboratory driver at Los Alamos, unless, as proposed by LANL, work on a KrF driver is initiated. There are good and bad features to KrF, as there are for any laser, including neodymium glass. It is not yet clear whether a major investment in KrF or glass technology is warranted. Certainly, design studies on KrF and modest laboratory tests are justified and should be done at this time. The smaller ICF groups at the Naval Research Laboratory, the University of Rochester, and KMS Fusion also need access to adequate driver facilities. The Omega laser at the University of Rochester has recently benefited from a major upgrade. Both NRL and KMS Fusion would like to have improved drivers.

As the size and expense of ICF driver facilities grow it would appear sensible to operate with national facilities in much the same way that high energy physicists use large accelerators.

A possible course of action would be to encourage different laboratories to share a given driver facility. While this would save substantial construction costs, it would also slow down the rate of experimentation and perhaps hurt the creativity of the program to some degree. If the attainment of pellet ignition is delayed by several years as a result of too little opportunity for experimentation, the overall cost of eventually achieving ignition in the ICF program, which the Committee expects to be high, could be even higher if the number of available drivers is limited to one or two. The Committee has not yet had time to study the serious question associated with facilities sufficiently to make a recommendation, but we intend to address this subject in our final report.

The Committee was briefed on the theoretical and experimental efforts contained within the Halite-Centurion program and the Nova/PEBFA programs. While we are convinced that both programs will contribute significant new insight to the ICF feasibility, it seems clear that we will be left with a significant gap between them.

The question of high gain is likely to

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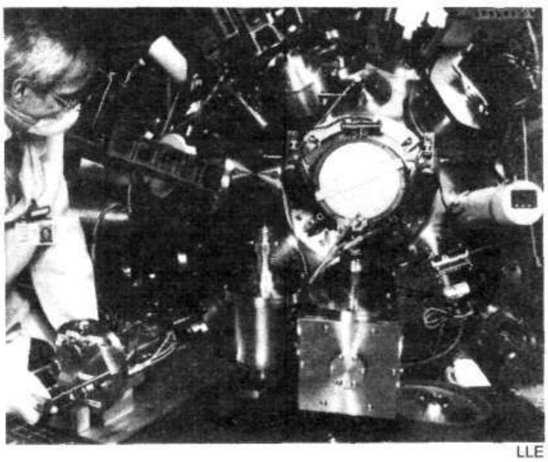
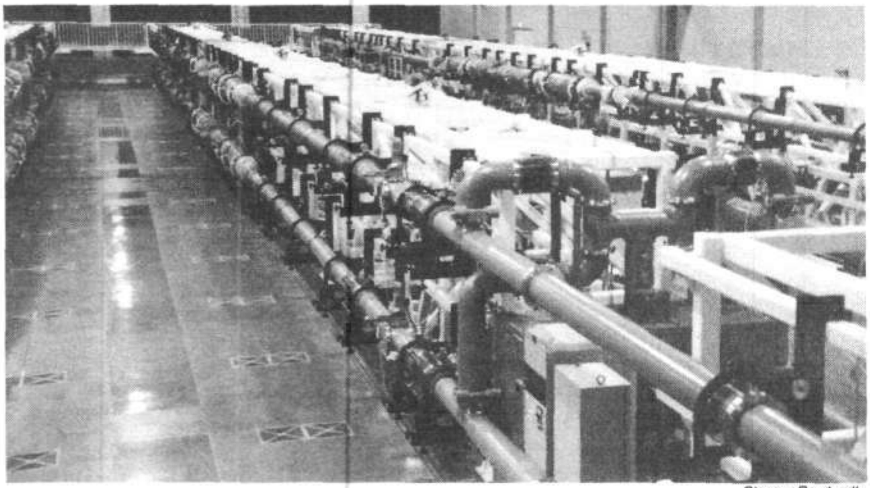

LLE

The University of Rochester's high-power Omega laser has demonstrated a new type of lasing medium that makes X-ray lasing possible at much shorter wavelengths than otherwise obtainable. Here, a researcher works with Omega's diagnostic system.

Osaka's Gekko XII Has Record Neutron Output

Osaka University's Institute of Laser Engineering reported in February the production of a record number of fusion neutrons—1.25 trillion per shot—with the 12-beam, 50-trillion-watt Gekko XII glass laser system. The record thermonuclear yield was achieved by irradiating a minute glass microballoon, containing deuterium-tritium fusion fuel, with the frequency-doubled output of the Gekko.

The Osaka experiments are most significant in terms of developing laser fusion as an economical source of commercial electricity, because they used a minimum energy input to achieve a maximum energy gain. Specifically, they obtained a carefully controlled compression of the fusion fuel using quasitailored laser pulses for multiplexing shock implosion waves and a minimum of preheat.



Steven Bardwell

Japan's 12-beam Gekko XII glass laser reached a record number of fusion neutrons. Shown here is the laser amplifier system.

Of the two main approaches—inertial and magnetic confinement—to harnessing the virtually unlimited energy potentials of thermonuclear reactions, the inertial confinement approach offers the most near term prospect for achieving electricity production at half the cost of existing sources. Inertial confinement, using intense laser or charged particle beams to compress and heat hydrogen to fusion conditions, has been pursued along two distinct lines of research: direct-drive targets and indirect-drive targets.

In direct-drive targets, a tiny sphere containing hydrogen fusion fuel is directly irradiated by a large number of laser beams. The ablation of the material from the surface of the sphere or target pellet causes the generation of imploding shocks that compress and heat the rest of the target.

In indirect-drive targets, the incident laser beams are first transformed into X-rays. The X-rays then irradiate the fusion fuel pellet to achieve the compression and heating of the fusion fuel.

The mainline, U.S. inertial confinement fusion programs at the national weapon laboratories of Livermore, Sandia, and Los Alamos have primarily pursued the indirect-drive approach. The Japanese, on the other hand, have pursued both types of inertial confinement fusion.

Isentropic Compression

A key requirement for both types of inertial confinement fusion is to achieve the shock compression process with very little heating of the fuel. Fuel heating should occur only when the maximum compression is attained, and then should heat only a small portion of the compressed core of the fusion pellet. This type of compression, with little preheating, is termed *isentropic compression* and provides the basis for the highest energy gain. Gain is measured by the ratio of the fusion energy generated to the total laser energy utilized to drive the implosion.

When hydrogen is compressed to high densities—up to 50 times that of lead—only a small portion of fusion fuel need be brought to the 100,000,000° Kelvin ignition temperatures in order for most of the fuel to undergo thermonuclear fusion. This is

Japan Accelerates Fusion Program

The Japanese have announced plans to accelerate their growing fusion research effort with the construction of a new institute and experiment that go beyond that of the massive JT-60 tokamak. The expansion was officially recommended by the Science Council of the Ministry of Education, Culture, and Science.

The new program will probably be located at Nagoya University's Institute of Plasma Physics. According to the recommendation of the 27-member Science Council, the new experiment will be based on a more advanced design than that of the tokamak, which has provided the mainline approach to the development of magnetic fusion plasmas over the past two decades. Japan's giant JT-60 is on the same scale as the Western European JET project, which will achieve fusion breakeven and ignition in the next few years. Both tokamaks are significantly larger than the Tokamak Fusion Test Reactor at the Princeton Plasma Physics Laboratory.

Plans are also under way for the expansion of the JT-60 facility by the Japanese Atomic Energy Commission. The new experiment will be based on an advanced design that is a hybrid of the tokamak and the stellarator—both of which are donut-shaped magnetic bottles. The hybrid will also probably utilize the new design of helical-shaped force-free magnetic field coils.

because the heated core will generate a thermonuclear burn wave that will heat and react with the remaining outer layers of cold compressed fuel before the pellet blows up. In this way isentropic compression uses a minimum energy input to achieve a maximum energy gain.

Ablation and Shock Multiplexing

These direct-drive Osaka laser fusion results are most significant in that they were obtained utilizing conditions that most closely approximate the desired isentropic compression process—ablative implosion and shock multiplexing. Most previous laser fusion implosions have been obtained with "exploding pusher" types of targets, where the incident laser radiation heats and compresses all of the fusion fuel simultaneously. Lawrence Livermore National Laboratory's Nova laser—the world's highest power laboratory laser—recently obtained 11 trillion fusion neutrons using an exploding-pusher-type target. But the exploding pusher approach cannot reach the high gains that result from the alternative isentropic implosion approach.

To obtain an isentropic compression, the incident laser energy must be carefully tailored in space and time so that it is absorbed only on the surface of the fusion pellet. This type of laser energy deposition is called *ablation*. Furthermore, the incident laser pulse must be further tailored so that a series of weak implosion shocks are generated.

If all of the shocks come together only when they reach the center of the pellet, the process is termed *shock multiplexing*. The coalescence of the shocks at the center of the pellet results in local heating of the target core and the generation of the thermonuclear burn wave. That is, the separate weak shocks do not heat the fuel while they pass through it; they achieve heating when they combine at the center of the fuel.

The 'Green' Implosion

The normal output of Osaka's Gekko XII is 1.05-micron wavelength laser light. By utilizing frequency doubling crystals, the Osaka scientists were able to transform this wavelength to a .53-micron wavelength—a wavelength

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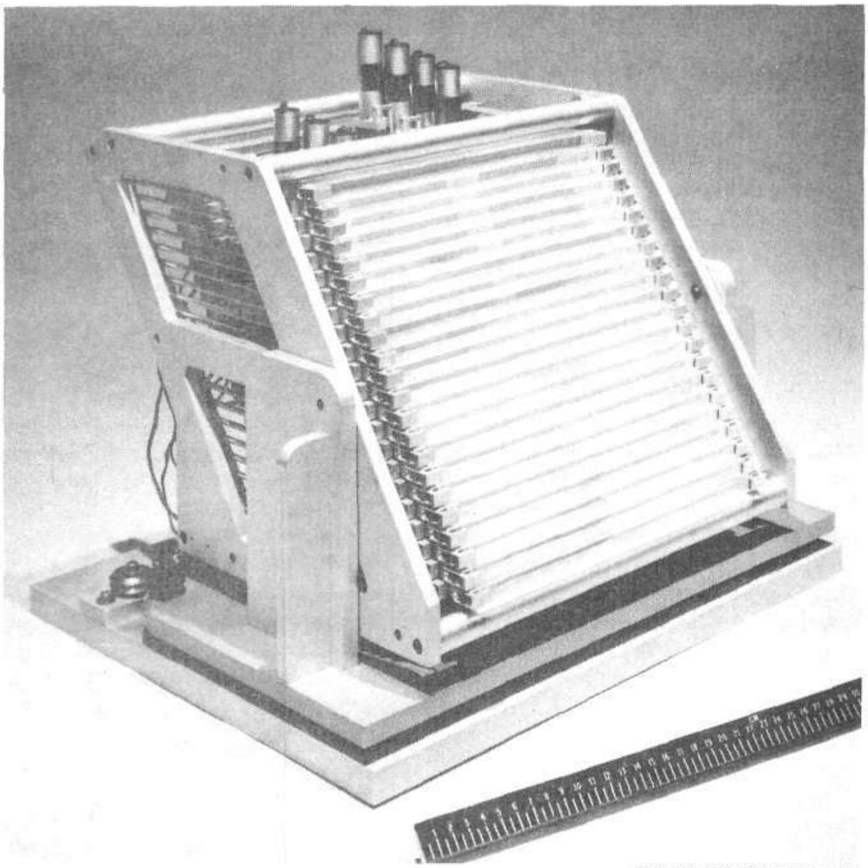


Courtesy of S. Obenschain/NRL

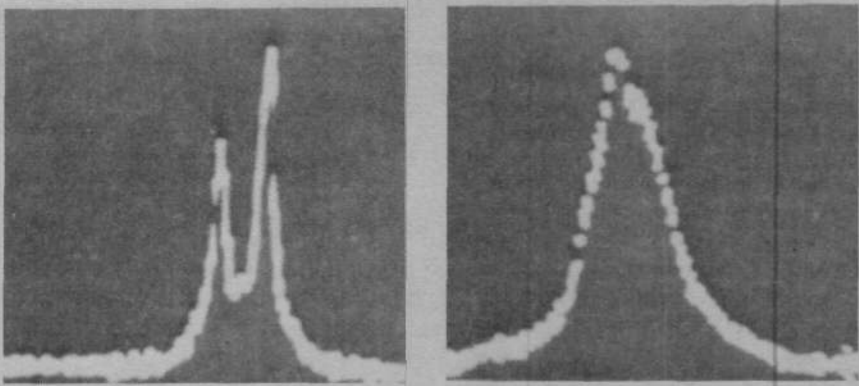
Induced spatial incoherence, which improves the focal intensity of a laser beam by as much as a factor of 100, is produced in this reflective echelon, a device that breaks up the incident laser beam and imposes different optical delays on sections of it.

NRL Uses 'Incoherence' To Improve Laser Fusion

Scientists at the Naval Research Laboratory (NRL) in Washington, D.C., have experimentally demonstrated a new technique for improving the efficiency of laser fusion that, ironically, consists of disrupting the coherence of laser light in order to improve its absorption efficiency by a fusion fuel target. This new approach, which is also being developed by Japanese fusion researchers at Osaka University, promises to greatly improve the prospects for "direct-drive" inertial confinement fusion.

In inertial confinement fusion, a minute pellet containing hydrogen fusion fuel is compressed to a density 1,000 times that of ordinary liquids by the action of multiple laser beams. This compression process requires that a few million joules of energy—the energy an ordinary car would possess moving at a velocity of several hundred miles per hour—be focused onto the surface of the fuel pellet with a high degree of uniformity. This means that irradiation uniformities of 1 to a few percent are needed.

An ordinary, coherent laser beam cannot fulfill this requirement, because its intensity nonuniformities are far too great. Therefore, it was thought



(a) Modulated beam, no echelon (b) Modulated beam with echelon

How the echelon device improves the focal intensity of the laser beam can be seen in these two focal profiles.

that the only way to obtain direct-drive inertial confinement fusion was to resort to an undesirably large number of individual beams. The mainline U.S. laser fusion program has attempted to get around this problem by using indirect-drive targets, in which the laser light is first transformed into X-rays that then irradiate the fuel.

Although successful, the indirect X-ray drive approach has drawbacks. First, only a portion of the incident laser energy can be converted into X-rays that actually irradiate the fusion fuel pellet. Furthermore, the container, or "hohlraum," in which this conversion process takes place can be quite complicated and expensive to design and make.

Induced Spatial Incoherence

The new experimental method recently demonstrated at NRL increases the deposition uniformity of single laser beams and thus promises increased possibilities of realizing the potentially more efficient, direct-drive approach to inertial confinement fusion.

Called induced spatial incoherence or ISI, the technique was first proposed by Drs. R.H. Lehmberg and S.P. Obenschain in *Optics Communication* (Vol. 46, p. 27, 1983) and demonstrated in experiments over the past year on the NRL Pharos III laser.

The technique breaks the original laser beam up into hundreds of beamlets, each one of which is then subjected to a slightly different optical delay. When the beamlets are recombined by a focusing lens, the electromagnetic waves in each beamlet are out of phase with those in the other beamlets. This purposeful introduction of spatial incoherence in the recombined beamlets leads to a "mixing up" of the original beam intensity nonuniformities. The result is an overall increase by a factor of 100 in the laser beam uniformity.

Experimentally, induced spatial incoherence is obtained with an optical array, called the echelon, in which hundreds of slabs of optical material displaced in a stepwise fashion simultaneously break up the incident laser beam and introduce the required optical time delays.

The National Research Laboratory results will eventually be utilized by laser fusion programs throughout the world to explore the potentials of direct-drive inertial confinement fusion.

—*Charles B. Stevens*

Combining Inertial and Magnetic Fusion

A new approach to fusion, combining inertial and magnetic confinement, is under development by the Japanese using the long wavelength carbon dioxide laser.

Research results over the past decade have shown that the wavelength of carbon dioxide laser light is too long to efficiently ignite conventional types of inertial confinement fusion targets. In the early 1980s, Dr. Friedwardt Winterberg, of the Desert Research Institute at the University of Nevada in Reno, and the Fusion Energy Foundation proposed utilizing magnetic fields in inertial confinement fusion targets so that the combined magnetic and inertial confinement fusion targets could provide the means to overcome the limitations of longer wavelength carbon dioxide lasers.

This is exactly what the new Japanese experiments indicate.

Researchers at Osaka University's Institute of Laser Engineering recently reported significant experiments in which it is believed that laser-induced magnetic fields are producing magnetic plasmas that are sustained up to 10 times longer than the incident carbon dioxide laser pulse. The targets consist of 3-millimeter-diameter hollow plastic spheres.

Ironically, as the Japanese are moving forward with the carbon dioxide laser, the United States is dismantling its large Antares carbon dioxide laser facility at Los Alamos National Laboratory. Antares is the world's most powerful carbon dioxide laser, and detailed calculations were carried out by Dr. Irv Lindemuth of Los Alamos National Laboratory on the type of magnetic inertial confinement fusion targets that the Japanese are now investigating.

The Japanese experiments are discussed in greater detail by A. Hasegawa et al. in *Physical Review Letters*, Vol. 56, p. 139 (1986).

Air Force Demonstrates Phased-Array Laser

by Charles B. Stevens

In a series of experiments last year, scientists at the U.S. Air Force Weapons Laboratory in Albuquerque, N.M., demonstrated that the phased-array techniques utilized in radars could be extended to lasers. This revolutionary development dramatically increases the output power density—brightness—of lasers and their optical components, while simultaneously decreasing system cost.

The potentials of phased-array techniques arise from the fact that both radars and lasers generate coherent electromagnetic radiation outputs. "Adding" coherent beams of electromagnetic radiation in phase with one another produces a nonlinear increase in their power density, as shown in the accompanying Air Force illustrations.

Because lasers emit coherent beams of light, it is possible to "phase" a large number of small lasers together to form one, much more powerful output beam.

Phased arrays of separate laser, telescope, and mirror modules lead to the coherent addition of the output. If N is the number of beams or modules combined in the phased array, the resulting output will be increased by N^2. That is, phasing together four small lasers or mirrors will result in a combined beam output 16 times more intense—a 16-fold increase in brightness and peak intensity—than that of an individual laser.

The potential advantages are immense. Smaller unit sizes for lasers, mirrors, and telescopes permit the implementation of mass production techniques with a consequent orders-of-magnitude decrease in cost per achieved output. Modular scale-up makes practical larger effective diameters and outputs than those allowed by single piece units.

Figure 1 depicts a system in which six small telescopes were phased together to synthesize a laser output equivalent to an aperture 36 times greater. This Air Force Weapons Laboratory illustration of a phase array demonstrated active control of independent telescopes with optical laser light. In this particular PHASAR series of in-house experiments, three independent 10-centimeter Mersenne telescopes were utilized, together with a multiline argon ion laser, a computer-controlled electromechanical phasing system, and diagnostics equipment.

This experimental series demonstrated essentially zero optical path difference between telescopes and simultaneous phasing of multiple wavelengths. In other words, it obtained phased-array synthesis from an input of differing, though harmonically related, laser wavelengths.[1]

Compared in Figure 2 are computer-generated graphs of the experimentally measured laser beam intensity distribution of the output of three telescopes that are not phase arrayed (a) and the same three telescopes arrayed in phase (b). The output intensity of the phased array is nine times that of a single unit.

Laser Coupling

In order for generators (like laser cavities or microwave tubes utilized in radars) or receivers (like mirrors in the case of lasers and antennas in the case of radars) to be arrayed in phase, each of the system elements must be controlled with an accuracy at least equal to the wavelength of the electromagnetic wave being utilized. Radars operate with electromagnetic waves in the centimeter range. The challenge of extending phased-array techniques to lasers involved increasing positioning accuracies from a fraction of a centi-

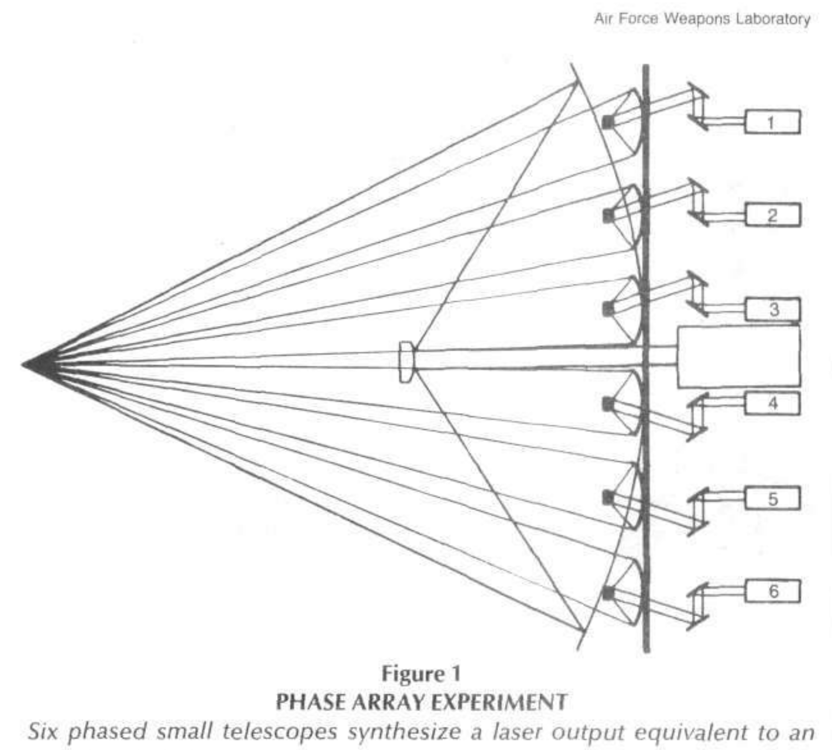
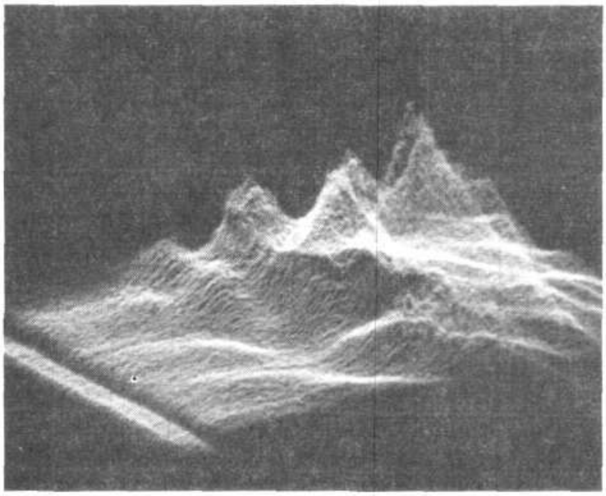
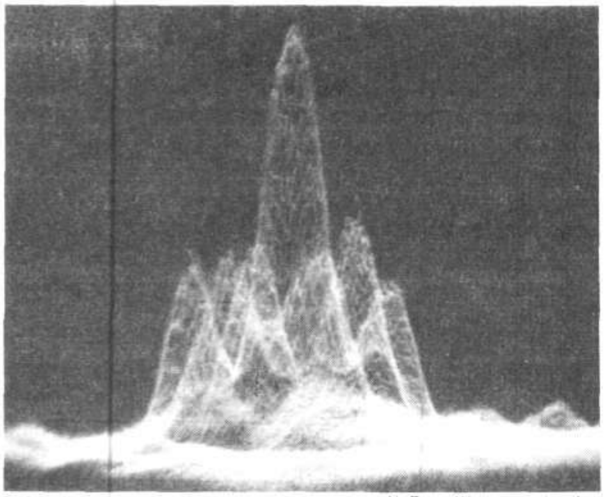


Figure 1
PHASE ARRAY EXPERIMENT
Six phased small telescopes synthesize a laser output equivalent to an aperture 36 times greater.



(a)



(b) Air Force Weapons Laboratory

Figure 2
PHASE ARRAY VS. NONPHASE ARRAY
These computer-generated graphics are from three telescopes where they are not phase arrayed (a), and where they are arrayed in phase (b).

meter to a fraction of a micrometer—the wavelength of laser light outputs.

When three laser cavities are coupled in a phased array, it permits modular scale-up to very high total power using moderate power modules that are much easier to develop and cheaper to build. This technique overcomes the power scaling limits that constrain individual laser modules to power levels below those required for beam weapon missile defense.

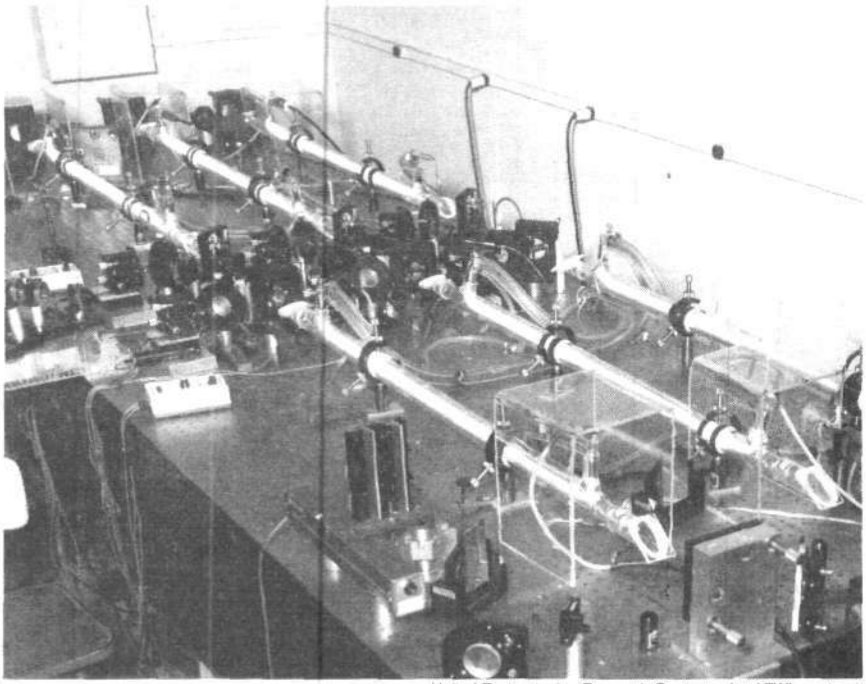
In this Air Force concept, called adjoint hole-coupling, the optical resonator for each laser module is optically coupled to its two nearest neighbor resonators through holes in the output or "scraper" mirror.

The output beam "footprints" from the experiment are shown in Figure 3.

Near-term Implications

Phased-array techniques are already revolutionizing the technology for space-based laser mirrors. For example, mirrors with diameters in the range of 10 to 100 mirrors are extremely difficult to manufacture and deploy. But by coupling an array of 10 to 100, 1-meter mirrors together, the same effective laser brightness can be attained. The smaller, 1-meter mirrors can be mass produced and readily deployed.

The result, as shown in recent studies by the company TRW Inc., is that virtually any desired laser brightness can be practically obtained with "segmented" phased-array mirrors using any wavelength laser, at costs orders of magnitude less than those suggested by previous calculations. The lethal range of a laser fighting mirror configuration is directly proportional to its effective diameter. Thus, for example, 100 1-meter mirrors in a phased array could attain the same effective range as a 1-meter-diameter mirror.



United Technologies Research Center under AFWL contract

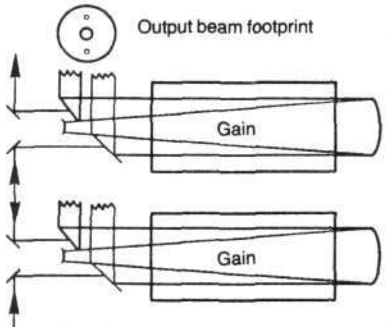
The facility that demonstrated laser coupling in a phased array. This experiment used six low-power, electrically excited carbon dioxide lasers. The optical resonators of these lasers are coherently coupled using the adjoint-hole coupling approach by the mirrors at the center left.

Alternatively, the rate at which targets can be killed is directly proportional to the laser system brightness. Increasing the effective mirror diameter from 1 to 100 meters, while keeping the firing range constant, would increase the laser system firepower by a factor of 100^2—10,000.

If the potential 100,000-beam output from a nuclear-bomb-powered X-ray laser module could be phase arrayed, then the overall output brightness could be increased to the 10^{39} watts per steradian range, which would be about 100 trillion times brighter than the Sun's output. This could provide a practical means for probing deeply within the Sun's outer plasma shell.

Note

1. *Military Space Newsletter*, Dec. 17, 1985.



Air Force Weapons Laboratory

Figure 3
ADJOINT HOLE-COUPLING
In this concept, the optical resonator for each laser module is optically coupled to its nearest neighbor resonators through holes in the output mirror.

U.S. Nuclear Test Budget Increased by $1 Billion

The U.S. Department of Energy has requested a total of $8.2 billion in the 1987 budget for Atomic Energy Defense Activities, the program which carries out underground nuclear testing. This represents an increase of roughly $1 billion from fiscal year 1986 levels.

On March 25, in testimony before the Senate Armed Services subcommittee, Lt.-Gen. James Abrahamson, director of the Strategic Defense Initiative, indicated just how far ahead the Soviets are in exactly this area. They may be well ahead of the United States in development of hydrogen-bomb-powered X-ray lasers, he said, and he backed up his assertion by reporting that the Soviets carried out an underground nuclear test with X-ray lasers for the first time in 1982. "We will not be able to do [this] until 1987."

Other informed sources have reported that in recent years the Soviet Union has conducted almost twice as many underground nuclear tests as the United States has.

Nuclear-Bomb-Powered Systems

The development of magnetic plasma lenses for focusing and electromagnetically pointing X-ray laser beams, along with other breakthroughs, has created the basis for producing hydrogen-bomb-powered X-ray lasers. Just one bomb could generate tens of thousands of highly lethal beams, increasing the overall potential brightness to a trillion times that of a simple hydrogen bomb. Such a system, then, has the potential firepower to destroy virtually the entire world inventory of ballistic missiles and their warheads at any stage of their flight.

Ironically, the impact of these advances would have a far greater adverse effect on the Soviet Union's military capabilities than those of the United States. The existing Soviet order-of-battle is designed to achieve a surprise first strike that would destroy Western strategic capabilities. Thus, Soviet first-strike strategy would utilize a rapid series of massive missile salvos. The nuclear X-ray laser promises to be most efficient and effective against precisely this type of attack.

For example, by deploying only a handful of nuclear X-ray modules on submarine missiles in the Arctic—a deployment that would be virtually impossible to detect—the entire Soviet inventory of ICBM warheads and decoys could be taken out during the 20 minutes that they pass through space on their way to North America.

In such a case, a Soviet first strike would end up significantly depleting Soviet military capabilities, and not those of the United States. Even if a deployment of X-ray lasers with this kind of firepower had a very low probability, it would nonetheless go a long way toward undermining the Soviet first-strike strategy.

In addition to X-ray lasers, the U.S. DOE Defense Program's nuclear-directed energy weapon (NDEW) program also includes devices for hydrogen-bomb-powered systems that produce huge bursts of microwaves, charged particle beams, optical laser beams, swarms of hypervelocity projectiles, and directed pulses of neutrons from spin-polarized fusion fuel.

Osaka's Gekko XII

Continued from page 22

which is termed "green" by laser specialists. With this shorter wavelength, it is possible to obtain an ablative type of laser energy deposition on the pellet with a minimum of preheating.

The Osaka researchers also were able to tailor the incident laser pulse to produce the conditions for shock multiplexing. This was reflected by the fact that the fusion energy output fell by a factor of 10 when the incident laser pulses were shortened from ¾ billionth of a second to ½ billionth of a second. The shorter pulses did not produce the required series of converging shocks.

The success of these experiments demonstrates that Japan continues to maintain a laser initial confinement fusion program of the first rank, developing both the direct and indirect drive approaches.

—*Charles B. Stevens*

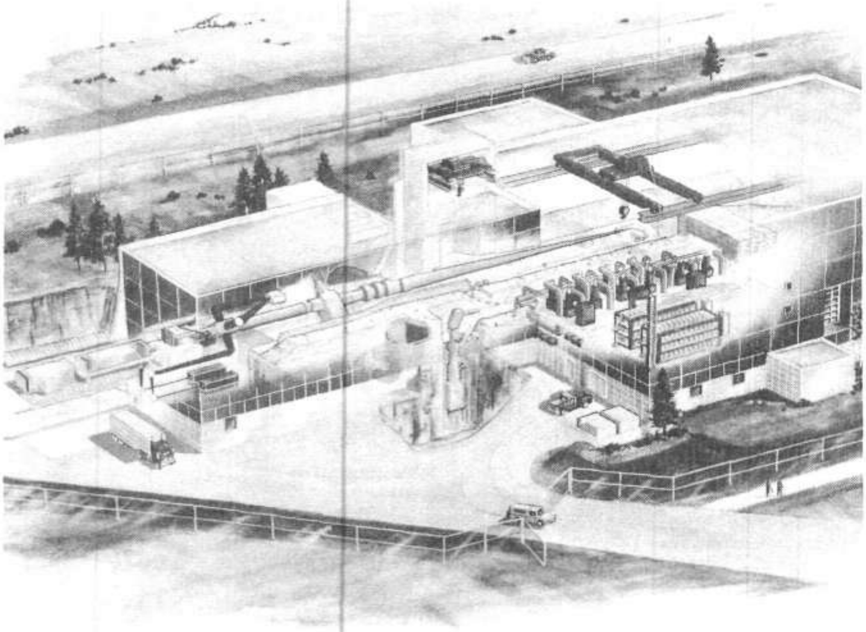
SDI Funds Neutral Particle Beam Facility

Continuing progress in the neutral particle beam weapon effort has led the Strategic Defense Initiative to fund the construction of a 57,400-square-foot demonstration facility that will house the most advanced particle beam research system outside of the Soviet Union.

Neutral particle beams, whose technology was pioneered by the massive Soviet directed-energy weapon effort, have long been recognized as a potentially effective means of destroying offensive nuclear missiles. More recently, it has been found that even low intensity neutral particle beams could be utilized to discriminate between real warheads and decoys in space so that other antimissile weapons could be efficiently used to destroy them.

The new $6 million contract will provide the facilities for developing neutral particle beams for space-based demonstrations of target discrimination by the end of this decade.

"This is one of the Strategic Defense Initiative's largest programs," said Richard Burick, the Los Alamos deputy associate director for Directed Energy Weapons. "The goal is to develop the technology needed to test an experimental neutral particle beam system in space."



Los Alamos National Laboratory

Artist's illustration of the demonstration neutral particle beam facility.

How Neutral Particle Beams Work

Ordinarily, high energy charged particle beams do not propagate very far through the vacuum of space. This is because the like electrical charges, which make up the beam, repel each other. Neutral particle beams overcome this problem by neutralizing the accelerated charges prior to their release into space.

Neutral particle beams have long been used to heat thermonuclear plasmas in magnetic confinement systems, like the tokamak. In the tokamak the neutralization of the beam permits it to penetrate the magnetic "bottle" containing the highly ionized hydrogen gas. As with other particle accelerators, in the neutral beam system, the first step is to accelerate charged particles to near the speed of light by the action of intense electric fields. However, the resulting charged particle beam is then passed through a gas cell in which the accelerated charges exchange electrons with neutral atoms. The result is that the charged particle beam is transformed into a beam of high energy neutral atoms traveling at near the speed of light. It is this beam of neutral atoms that can penetrate magnetic bottles and propagate over long distances in a focused beam through the vacuum of space.

Lethal to Missiles

Neutral particle beams are one of the most efficient methods of disabling ballistic missiles and their nuclear warheads. While laser beams have to deposit sufficient energy to mechanically disassemble nuclear missiles, neutral particle beams can achieve what is called "electronic" kills with far less deposited energy.

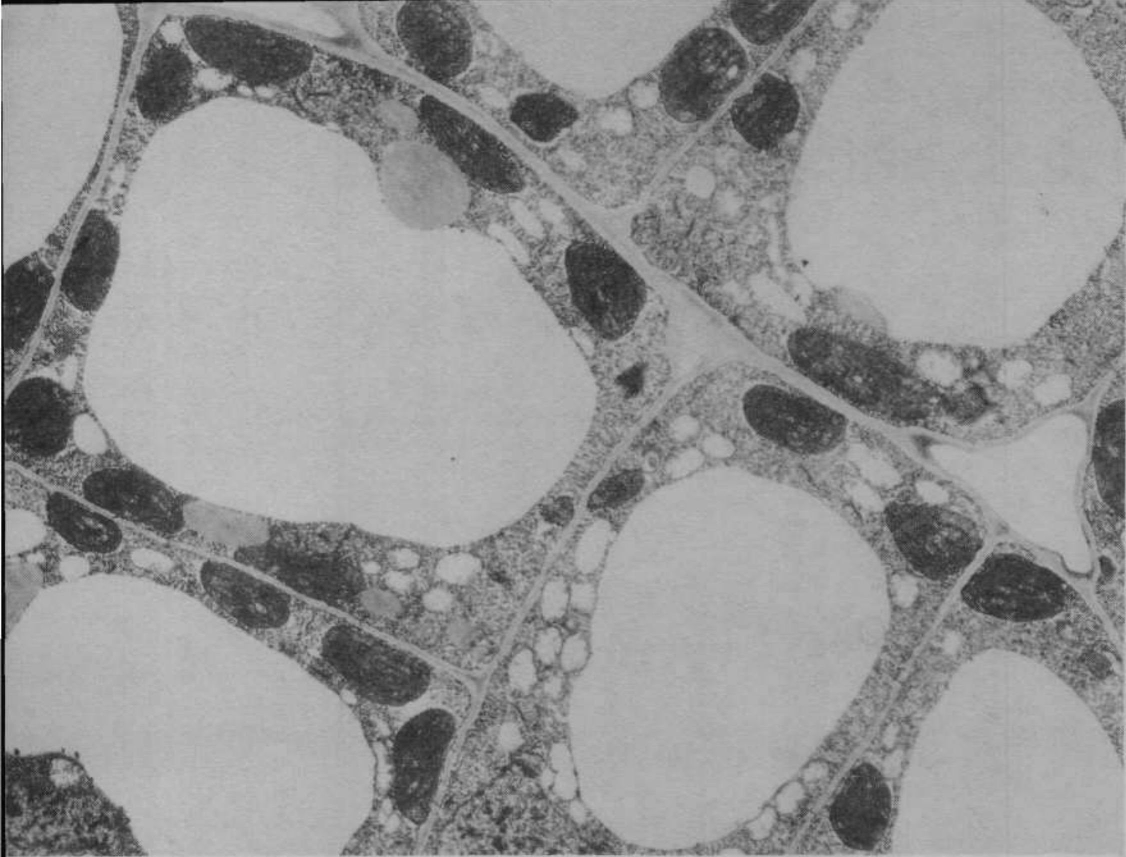
In general, neutral particle beams will penetrate far into the interior of any missile or warhead before its energy is dissipated. The intense radiation generated by the neutral particle beams within the deep interior of a missile or warhead will cause any electrical or electronic circuit there to be destroyed or at least critically disrupted to a point where the missile or warhead fails to function.

This same penetrating capability makes the neutral particle beam a major candidate for what scientists call target discrimination of incoming threat clouds, a lightning-fast method of sorting out decoys from real warheads. "Neutral particle beam systems may well emerge as key elements in target discrimination, which is a major technical challenge facing SDI researchers," said Los Alamos program engineer Jorg Jansen.

In this case, neutral particle beams would "interrogate" incoming warheads that are moving through the 20 minutes of the midcourse phase—the longest part of an ICBM's flight through space. Traveling at near the speed of light, even diffuse neutral particle beams would penetrate and react with the nuclear material of an ICBM warhead. The resulting minute bursts of gamma rays and neutrons produced could be detected by space-based sensors over extremely long ranges.

These gamma ray and neutron signals would then provide the means to locate and discriminate between decoys and warheads, because the essential size and material differences between decoys and warheads would result in different signals for each.

—Charles B. Stevens



Dr. Jeremy Burgess/Science Photo Library

Transmission electron micrograph of mesophyll tissue, the main photosynthetic tissue of a plant, which lies immediately below the leaf surface. The dark shapes are chloroplasts.

Scientists are beginning to solve the mystery of photosynthesis, using the same advanced spectroscopy techniques of nuclear magnetic resonance that doctors use to probe the human body.

The Geometry of Photosynthesis

by Ned Rosinsky, M.D.

The Sun does work on the Earth's biosphere by providing a constant stream of sunlight, photons, which power the photosynthesis of green plants. In this way begins the food chain that ultimately provides all the food consumed by both animals and plants on this planet. However, this idea leaves out the work done on the photons by the biosphere in its own creation, work that is of a geometric nature. Recent developments in laboratory techniques that vastly refine observations of the initial events in photosynthesis, including extremely rapid pulsed laser (coherent) light input and nuclear magnetic resonance devices, have shown that green plants in fact do considerable work on the incoming photon stream. This work takes the form of various transformations, including the coherent concentration of photons, which in turn increases the potential for useful work.

Before describing the recent laboratory advances, it is important to schematically outline the main processes known to be involved in photosynthesis (Figure 1). Overall, visible frequency photons in the red or shorter wavelengths are absorbed by plant pigments such as chlorophyll-protein complexes, which are embedded in specialized membranes in the plant cell. This absorption results in the pigment becoming temporarily transformed to a higher state of work potential. The pigment is then able to transfer this work potential by inducing an electromagnetic (chemical) change in water or other substances, bringing them up to a higher work potential. This starts an entire chain of chemical changes that ultimately creates certain specific high-energy substances, such as sugar, which are long-term, stable work-potential storage substances usable as food (work-potential sources) either by the plant itself or by animals that consume the plant.

The part of this overall process focused on here is the initial absorption of photons by the pigment, and the channeling of these photons as preparatory to chemical changes that are initiated by the activated pigment. Such events are of particular interest because, as noted above, the biosphere requires the photosynthetic transformation of photon work potential into biological work potential, as the ultimate source of all food for living organisms; and future improvements in agricultural efficiency based on biotechnology will depend on the depth of our understanding of these biological activities. In addition, the study of these particular transformation processes should provide clues for understanding the most fundamental questions about

(a)

$$6CO_2 + 6H_2O \xrightarrow{h\nu^{\Delta}} C_6H_{12}O_6 + 6O_2$$

Figure 1
MAIN PROCESSES INVOLVED IN PHOTOSYNTHESIS

The chemical reduction of carbon (a). Carbon from the air, in the form of carbon dioxide, is chemically changed using the energy from sunlight, in a process termed reduction. The oxygen is removed from CO_2, and the carbon is ultimately used to form sugar, $C_6H_{12}O_6$, a high energy compound, which the plant uses to store energy, and which can be consumed by other organisms and used as their energy source.

The overall carbon cycle in the biosphere (b). The box (left) signifies the biomass of photosynthetic organisms. These organisms take carbon dioxide out of the air, and in a complex process combine it with the hydrogen of water to produce organic compounds like sugar. These compounds are used as food both by photosynthetic plants and by nonphotosynthetic organisms (heterotrophs). If the compounds are used as energy sources in oxidative processes (referred to chemically as respiration), then the carbon is reoxidized to carbon dioxide and returned to the atmosphere.

Carbohydrates that are used as food enter into a complex network of interconnected chains of chemical reactions, both to produce energy and also to produce the many different kinds of substances needed for living tissue to grow and repair itself.

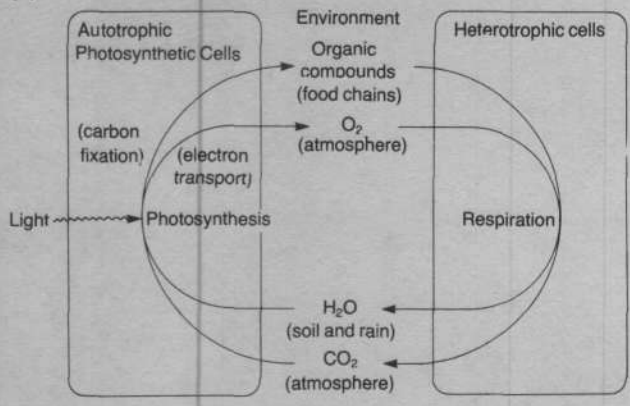
The excitation of an electron by the absorption of a photon (c). Photons are absorbed by the pigment chlorophyll in green leaves. The energy from these photons is subsequently used to chemically reduce the carbon in carbon dioxide, creating the high energy compound sugar. The initial event in this complex process, the absorption of a photon by chlorophyll, involves the excitation of an electron in the chlorophyll molecule, to a higher energy state.

An electron in ground state is shown at the lower level. The absorption of a photon raises the energy to the top. This high-energy state is unstable; the electron can either give up the energy as a photon (that is, reradiate the energy away in fluorescence), or it can transfer that energy to other molecules where the energy will be more stable. This latter process occurs in photosynthesis.

Chlorophyll molecule (d). The chlorophyll molecule is a large ring made up of smaller rings as shown, with a long extension called the tail.

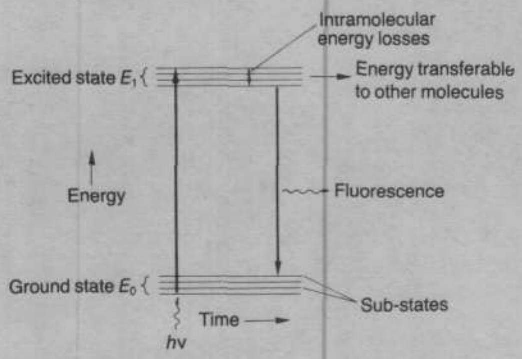
Action spectrum of photosynthesis, and absorption spectrum of chlorophyll a and chlorophyll b (e). The action spectrum is the relative rate of photosynthesis graphed against the wavelength of the light source photons. Photosynthesis is most efficient when the absorbed photons are of a wavelength of either 440 or 670 nanometers (upper curve). The specific absorption characteristics of chlorophyll a and chlorophyll b, the two most common chlorophylls in advanced green plants, are shown in the lower curves. The absorption characteristics of chlorophyll correlate closely to the action spectrum of the plant, an indication of the central role of chlorophyll photon absorption in plant photosynthesis.

(b) The overall carbon cycle in the biosphere

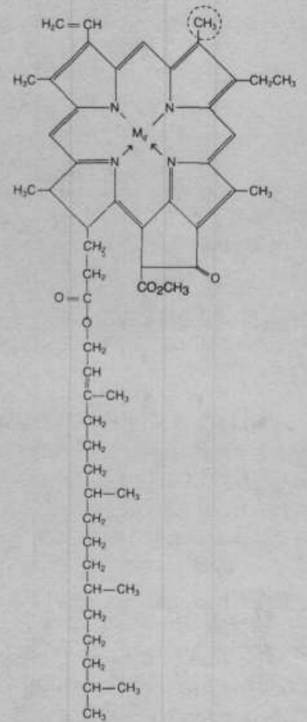


[^1H]*R. rubrum* 9.5 ± 0.5 9.1 ± 0.4

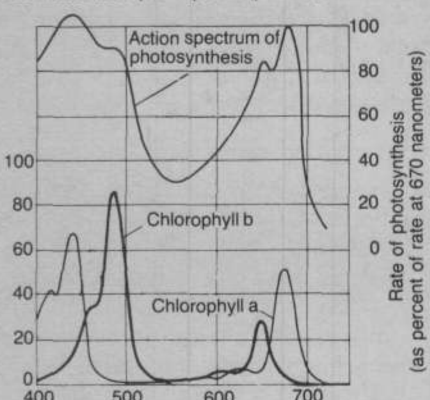
(c) The excitation of an electron by the absorption of a photon



(d) Chlorophyll molecule



(e) Action spectrum of photosynthesis



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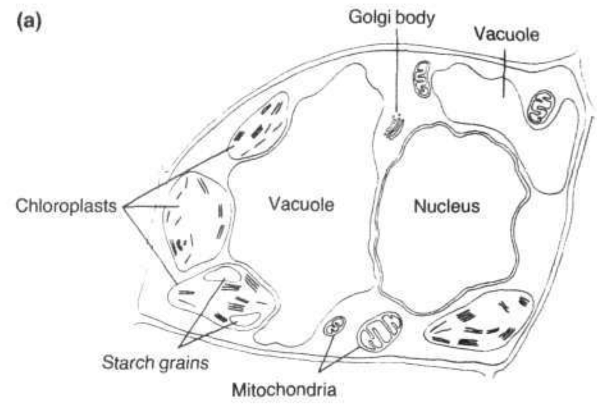
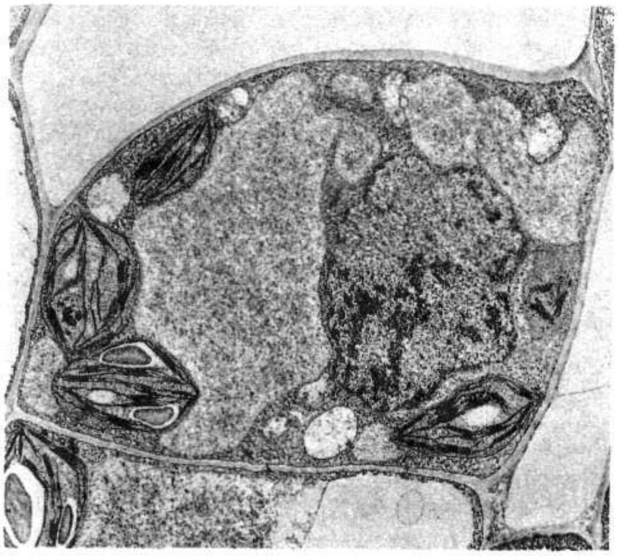
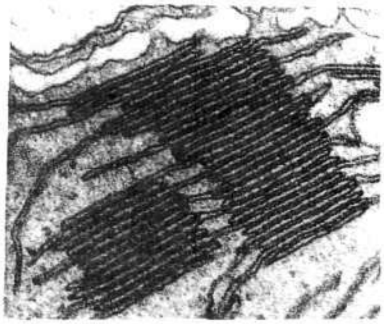
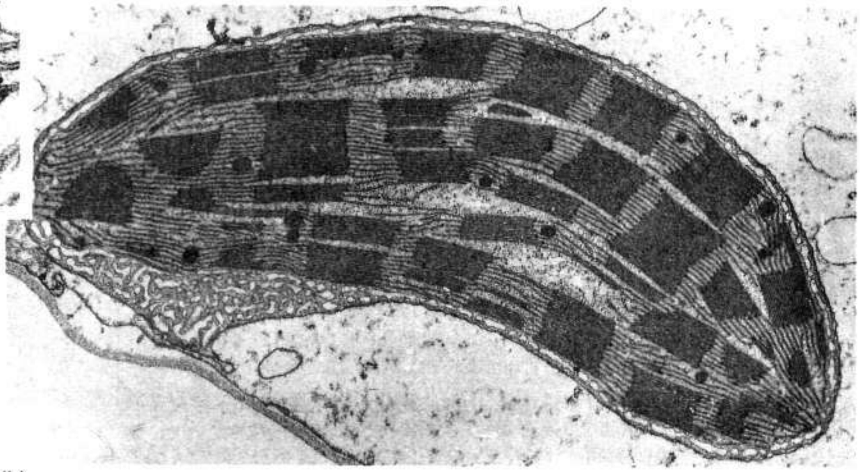








(b)

Figure 2
PHOTOSYNTHETIC MEMBRANE

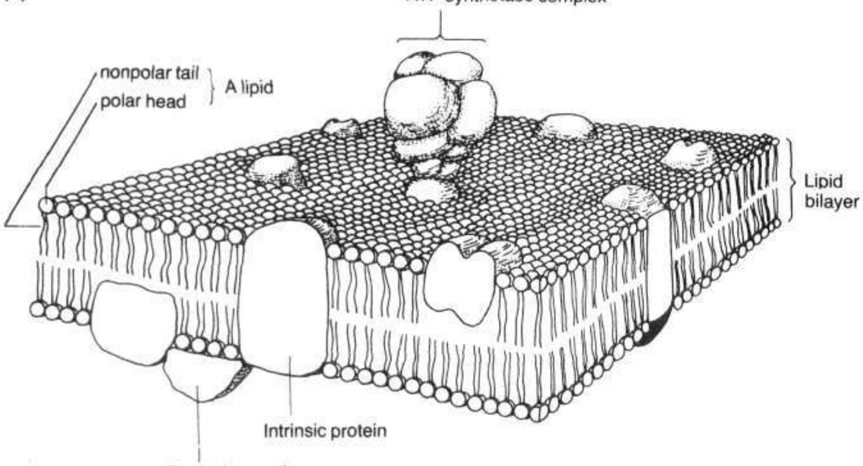
A photosynthetic cell from a tobacco leaf (a). Within the cell are several chloroplasts, organelles within the cell that engage in photosynthesis.

An enlargement of a chloroplast (b). Note that there is a delicate lacework running through the cell. This is the photosynthetic membrane system, a portion of which is enlarged in the inset.

Model of general membrane structures (c). Cross sections of sheets of membrane are represented here at higher magnification in a molecular model showing the molecular components hypothesized to compose the membrane. The diagram depicts two layers of lipid composing the membrane, which is studded with proteins shown here as globules. It is presumed that in the photosynthetic membrane, chlorophyll is attached to globular proteins that are present in the membrane.

Sources: Curtis, H. 1975. *Biology*, 2nd ed. (New York: Worth Publishers. pp. 101 and 146; Danks, S.M., Evans, E.H. and Whittaker, P.A. 1983. *"Photosynthetic Systems Structure, Function and Assembly"* (New York: Wiley and Sons). p. 16.

(c)



the living state: In particular, we will focus on the question of how the geometry of these transformations is related to the qualitative changes in biological work potential.

The Photosynthetic Unit

The smallest unit in the green plant that is capable of performing all the initial steps in photosynthesis, from light absorption to the use of the potential of that light for the electromagnetic transformation (increase of reducing potential) of substances like ubiquinone, is termed the photosynthetic unit (PTU). There are millions of PTUs in an average plant leaf cell: Each PTU contains from 300 to 1,000 molecules of chlorophyll, numerous proteins, other pigments like carotenes, membranes, water, and various ions. The PTUs are functional subunits of the photosynthetic membrane in the plant cell. This membrane is 60 percent protein and 30 percent lipid (Figure 2). Although the components of a typical PTU can be described in chemical terms, the reader is cautioned that the usual concepts of chemistry implied by such a listing are wrongheaded and obstruct a real understanding of the processes under consideration. Particularly misleading are the notions of isolated molecules as functional units or "things," and that such "things" interact according to the laws of statistics. In reality, what exists are processes of transformation, such as those described here.

A striking feature about the contents of the PTU is that one particular component, chlorophyll a (Chl a), is apparently present in two distinct forms. One form is termed antenna chlorophyll, and has a peak in its light absorption at a wavelength of 670 nanometers (nm); the other form is termed photo-reaction center chlorophyll a (PRC Chl a), which has a shift in its absorption spectrum changing its peak absorption to 700 nm.

These two forms can be separated by breaking up the PTU and isolating its main components under certain physical conditions. The portion of the PTU that contains the substances that are chemically reduced in photosynthesis, like ubiquinone (that is, substances that will then go on to start a chain of chemical reductions, ultimately producing sugar), is presumed to be the actual site within the PTU where such reduction goes on, and is therefore termed the photo-reaction center (PRC). The PRC can be further broken down to its molecular components, one of which is Chl a, and it is this particular Chl a that is termed PRC Chl a, and that is presumed to be the agent directly involved in reducing ubiquinone. Again, this PRC Chl a is also distinguished by having a peak absorption at 700 nm.

In contrast, the rest of the PTU, exclusive of the PRC, contains Chl a, which absorbs at 670 nm. This chlorophyll is apparently not involved directly in chemical reduction, but is known to be involved in light absorption. It absorbs light and then passes that electromagnetic potential on to the PRC chlorophyll, hence the term "antenna" chlorophyll. Of the 300 to 1,000 molecules of Chl a in each PTU, only 2 molecules are in the PRC while the rest is antenna chlorophyll. Thus most of the Chl a has a light-harvesting function, while only a very small amount of the total chlorophyll engages directly in chemical reduction.

What is the difference between these two types of Chl a, which have such different functions? The difference is *not* molecular. If PRC Chl a is removed from the PRC and isolated, it no longer has an absorption peak at 700 nm but rather at 670 nm, and it appears to be identical in every respect to antenna Chl a. This question has been intensively studied by Joseph Katz's group at the Argonne National Laboratory in Argonne, Ill., where numerous lines of investigation have converged on Katz's conclusion that the PRC Chl a consists of two molecules of Chl a that are in such close proximity to one another that they function as one electromagnetic unit. We will examine this point in detail, and use it as an illustration of the kind of crucial geometric transformation referenced above.

The Photon Trap

Katz hypothesizes that the difference in absorption peaks between antenna Chl a and PRC Chl a has a specific function, which is to concentrate and trap within the PRC the photon work potential gathered by the various antenna chlorophylls throughout the PTU. It is well established that the hundreds of antenna chlorophyll molecules in the PTU are each capable of absorbing a photon, becoming temporarily activated by the absorption, and then transferring the photon excitation to another antenna molecule. The photons, once absorbed, can be handed back and forth from one antenna molecule to another. This is because the emission frequency is approximately the same as the absorption frequency, peaking in the range of 670 nm. Eventually, a photon will be passed on to the PRC chlorophyll pair (termed the Special Pair or Chl sp). The photon quantum can be absorbed by the Chl sp, because the energy of the photon is slightly higher than the absorption peak of 700 (670 nm is slightly shorter than 700 nm, and a shorter wavelength photon is higher in frequency and therefore in energy than a longer wavelength photon).

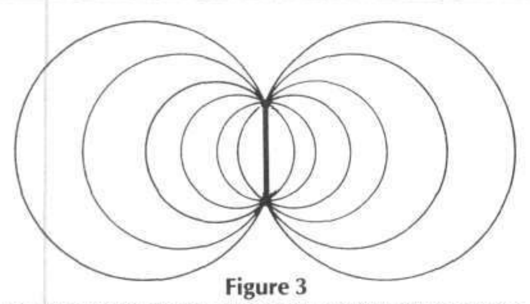


Figure 3
DIRECTEDNESS IN RADAR TRANSMISSION AND ABSORPTION

The intensity of a radar output varies with position around the transmitter. Different geometries of radar emitters (antennas) produce different patterns of isobars. This is also true of molecules that absorb or emit radiation.

Depicted here is a two-dimensional cross section through a three-dimensional field around a line antenna source. Note the directedness of the output, most of it going out sideways, very little straight up or down.

EPR Line Width and Size of Molecular Complex

The EPR of photo-excited chlorophyll gives information on the nature of the excited state. In the case of the isolated PRC chlorophyll, the question EPR can answer is whether the individual chlorophyll molecule is acting alone in the excitation, or if other chlorophyll molecules are participating in the excitation. The electron that is excited by the sunlight photon has a specific EPR spectrum that is different from the electron in its nonexcited state. That spectrum is affected by the surrounding nuclei with which it is interacting, or to which it is "coupled." These coupled nuclei may themselves be in a variety of energy states (spatial orientations with respect to the externally applied magnetic field). Therefore, different molecules in any given large sample will be in different states, resulting in slight differences in the spectrum of the excited electron. Thus, when the overall spectrum of a large sample of PRC chlorophyll is measured, one does not get a sharp absorption peak at only one frequency, but rather a closely packed group of absorption frequencies appearing as a rounded band of absorption. The larger the number of coupled nuclei in the molecule, the narrower this band will be, since there are more possible states in which these various nuclei can counteract each other's effects.

Empirically, as well as by the predictions of quantum mechanics, it has been found that the width of the peak is inversely proportional to the square root of the number of such coupled nuclei present. In the case of PRC chlorophyll, the width is 40 percent narrower than that of isolated antenna chlorophyll, suggesting that PRC chlorophyll consists of two molecules of chlorophyll closely coupled in the photo-excited state. The equation for this relation is $\Delta H_N = \Delta H_M / N^{1/2}$ in which the line width of the single molecule or monomer is termed ΔH_M, and the line width of the *N*-fold molecular aggregate is termed ΔH_N.

The table shows data from five different plants, four of which were tested both with usual hydrogen nuclei (^1H) and also with heavy hydrogen nuclei deuterium (^2H). The first column of numbers shows the PRC chlorophyll line width measured in units of gauss; the second shows the calculated special pair expected line width if $N = 2$, given the data of the monomer line width (the monomer line widths are not shown). The ratio of expected to actual results is shown in the last column, in which closeness to 1.00 indicates the correctness of choosing $N = 2$, or assuming that PRC chlorophyll is actually composed of two molecules of chlorophyll functionally integrated as a unit.

EPR LINE-WIDTH EFFECT ON CHLOROPHYLL MOLECULE

Organism	PRC Chlorophyll line width	Calculated special-pair	Ratio of expected to actual results
[^{1}H]*S. lividus*	7.1 ± 0.2	6.6 ± 0.3	1.08 ± 0.06
[^{2}H]*S. lividus*	2.95 ± 0.1	2.7 ± 0.1	1.10 ± 0.05
[^{1}H]*C. vulgaris*	7.0 ± 0.2	6.6 ± 0.3	1.06 ± 0.05
[^{2}H]*C. vulgaris*	2.7 ± 0.1	2.7 ± 0.1	1.00 ± 0.05
[^{1}H]*S. obliquus*	7.1 ± 0.2	6.6 ± 0.8	1.08 ± 0.06
[^{2}H]*S. obliquus*	2.7 ± 0.1	2.7 ± 0.1	1.00 ± 0.05
[^{1}H]HP700	7.0 ± 0.2	6.66 ± 0.3	1.06 ± 0.05
[^{1}H]*R. rubrum*	9.5 ± 0.5	9.1 ± 0.4	1.05 ± 0.07
[^{2}H]*R. rubrum*	4.2 ± 0.3	3.8 ± 0.1	1.10 ± 0.09

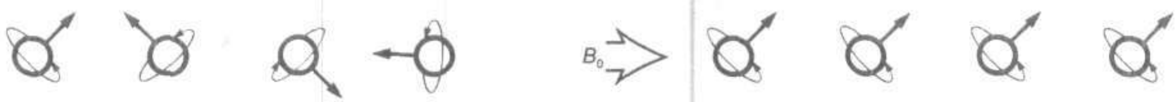
Source: Norris et al. in "Electron spin resonance and the origin of Signal I in photosynthesis." Proceedings of National Academy of Science, U.S.A., Vol. 68, p. 625 (1971).

However, even though the Chl sp can absorb photons of higher energy than its absorption peak, it cannot emit photons of energy higher than 700 nm, so it cannot transfer the excitation back to the antenna Chl, which absorbs only at 670 nm or higher energies. The excitation is thus trapped at the PRC. The overall effect of this process is to greatly concentrate photon excitation at the PRC, at the expense of a slight lowering of the energy of each photon quantum excitation; and the 700 nm photon quantum is still large enough to induce ubiquinone reduction at the PRC.

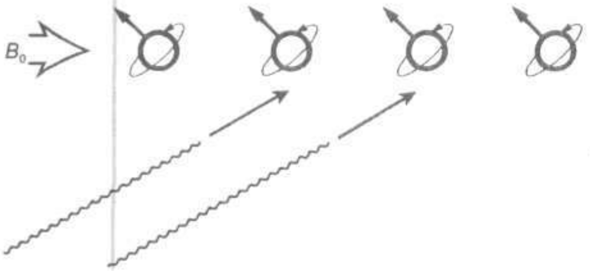
Research Methods

Although the above description may seem fairly straightforward (except for the admittedly confusing terminology), the methods of investigation used to derive these ideas are quite sophisticated. Since we are interested in small changes in absorption characteristics of aggregations of molecules, such as in the Chl sp, the usual methods of chemical analysis that are oriented to determining molecular structure are not appropriate. What is required are techniques that can quantify the number of molecules that are participating in a single excited state, or that are supporting one excitation.

In the case of this excitation, the result of the absorption of a photon in the visible region, the kind of change typical of this energy range manifests itself as an alteration in electron activity in the substance (here, chlorophyll). (Again, remember that although we are using the reductionistic terminology of chemistry to describe some of these activities, the underlying physical reality consists of transformation processes.) There are many things we would like to know about the functioning of the PTU. First, we would be interested in the manner in which light is absorbed, which is inherently a geometric question. We know from experience with radar, which utilizes the emission and absorption of electromagnetic waves with wavelengths in the centi-



(a) (b)



(c)

Figure 4

NMR AND ELECTRON PARAMAGNETIC RESONANCE

Electron paramagnetic resonance (EPR) is a variant of nuclear magnetic resonance, or NMR, that uses electrons rather than atomic nuclei. In NMR, the material to be investigated is placed in a strong, constant magnetic field. The components of the material, the atomic nuclei (shown here as spheres and labeled p *for proton and the electrons (e), will be affected by the magnetic field (B_0), because they are charged and are in general regarded as having a spin. They can actually be thought of as being microscopic magnets themselves. In (a) the nuclei are each shown as spinning spheres, with the curved arrow designating the direction of spin. The straight arrow shows the magnetic field created by the spinning charge.*

The atomic nuclei behave in some ways as magnets lining up when placed in a strong, externally produced magnetic field, as indicated by (b). As with ordinary handheld macroscopic magnets, the south pole will be attracted to an externally applied north pole. Also the magnet can be forced to reverse its position against this opposites-attracting position by doing work. In the microscopic realm, this is done by putting the work into the system in the form of photons (c), which have reversed the orientation of the nuclei. Because the atomic-scale phenomena are characterized by discrete jumps in state rather than by continuous changes, only certain amounts of change in the position of the nuclei or electrons are found empirically. Thus, only certain definite amounts of work can be done.

This means that only photons of a certain size will be absorbed by the spin-aligned nuclei (or electrons), which will move their position only in correspondingly discrete amounts. Since the "size" of a photon is its energy or frequency, only certain frequencies of photons are absorbed by the spin-aligned nuclei or electrons. As a result, each such spin-aligned material will have a certain absorption spectrum.

Different materials (that is, the nuclei of different elements) have different absorption spectra. NMR can distinguish among elements and also make more subtle distinctions. Because the work needed to change the direction of the spinning atomic nucleus depends on the strength of the external magnetic field, anything that alters that field will change the absorption spectrum. In particular, each nucleus will experience a local effect from the magnetic fields produced by nearby nuclei, which will add to the size of the externally applied field. Although this may seem to be a small effect, it is actually quite significant and can markedly affect the resulting spectrum.

Thus, NMR can be used to gauge the geometric relations among nuclei in a material. For example, the NMR of water shows that the nuclei are in a highly ordered condition, not randomly arranged.

meter to meter range, that the shape and direction of the aerial determine its efficiency of absorption. Equally important is the material of which the aerial is constructed. Since the geometric principles of antenna design hold fairly constant over a large range of radar and radio wave situations, we can presume that such geometric considerations are just as crucial at the smaller wavelengths of visible light, and in the context of molecular-size antennas. Since photons are waves or oscillations of electrical and magnetic fields, it makes sense that the orientation of an absorber with respect to the oscillation would be an important factor in establishing a resonance for absorption (Figure 3).

Although the radar model is certainly an oversimplification, it is useful to begin suggesting the kinds of geometrical questions we have to ask about the PTU. First, what is the geometry of the antenna chlorophyll molecules themselves. Second, what is their orientation with respect to each other, with respect to the membrane in which they are embedded, and finally with respect to the incident sunlight? Third, what is the geometric relation between the antenna molecules and the PRC chlorophyll? Fourth, what is the role of the many other substances in the PTU, including the proteins that are complexed with the chlorophyll, as well as several other pigments that are present?

There are several inherent difficulties in exploring these questions of geometry. First, the functional entity we are interested in is quite large by molecular dimensions. The determination of the large geometries of many biological entities, such as proteins and DNA, was made possible by X-ray diffraction of crystallized samples of material. However, the PTU is much larger than molecular diameters, and cannot as yet be crystallized. Another problem is that many

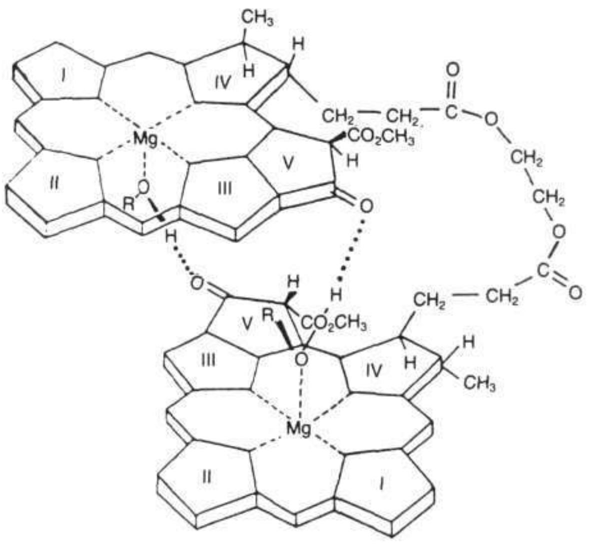


Figure 5
COMPARISON OF CHL SP TO SYNTHETIC DIMER
Two molecules of chlorophyll chemically bonded together are shown. The two plates can be folded, as shown, or openly spread out. The EPR data for the naturally occurring PRC chlorophyll is closely correlated to the artificially synthesized dimer in the folded form, both in terms of maximum absorption of photon frequency (700nm to 697nm), as well as in the EPR line width (7.0 to 7.5). These data strongly suggest a close relation of the naturally occurring PRC chlorophyll and the geometry of the relation of the two chlorophylls that is forced artificially by joining them together in a chemical bond and then holding them in the folded configuration.

of the component substances of the PTU cannot be reliably isolated, since they are in natural form bound to the photosynthetic membrane, and when they are removed they change their form so extensively that they cannot be readily utilized to infer dynamics in the living state.

Magnetic Resonance Technology

Many recent innovations in spectroscopic techniques relevant to these questions are related to nuclear magnetic resonance, and measure aspects of magnetic fields on the scale lengths of molecules. They can therefore indicate geometric ordering as well as electromagnetic interaction on these scale lengths, and can be used in the living state and while the pigment is electrically excited by a photon.

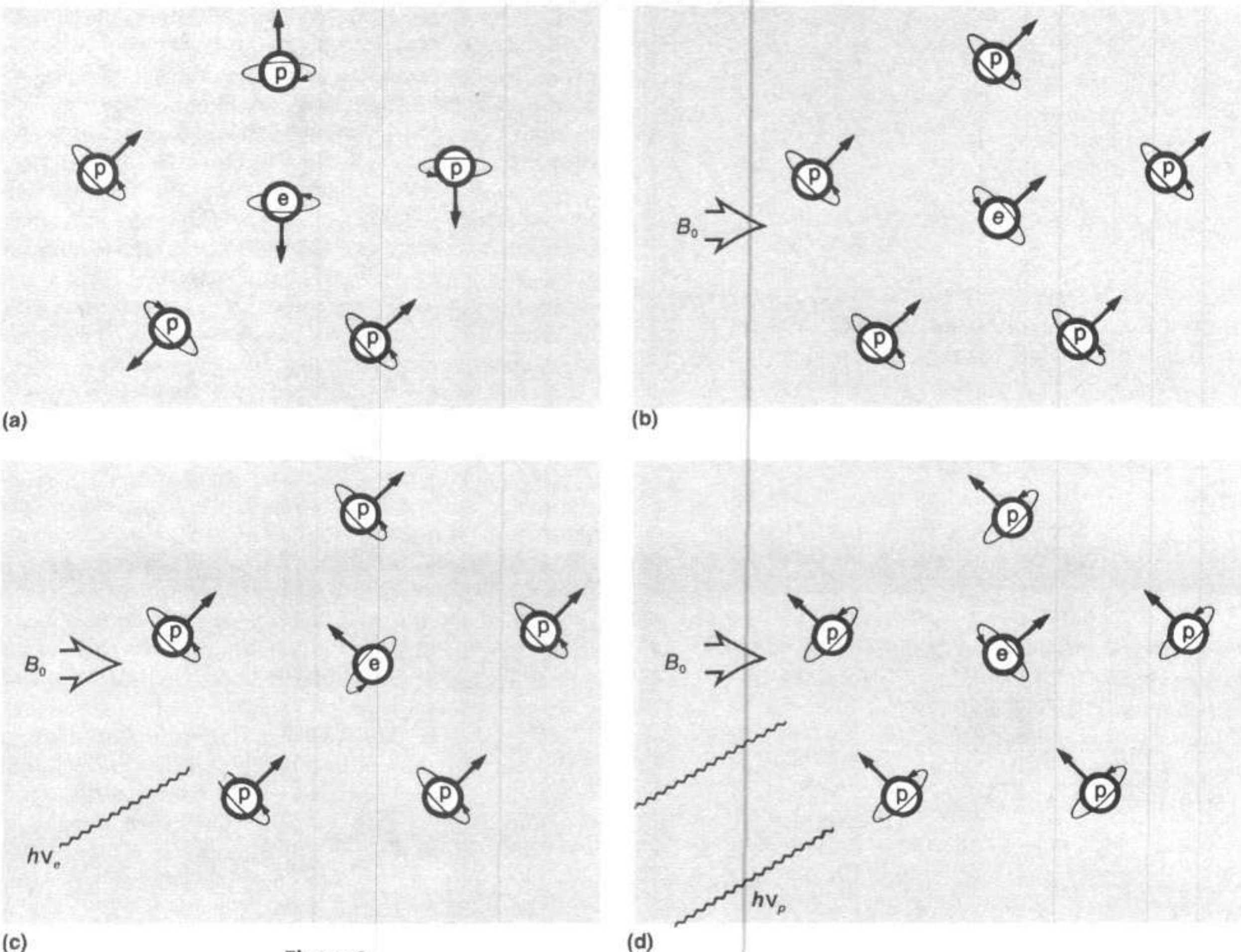
How is it that the antenna chlorophyll has a different absorption peak from the PRC chlorophyll? Joseph Katz at Argonne National Laboratory has done spectroscopic studies of PRC chlorophyll and concluded that the spectral shift is due to the close association of two molecules of chlorophyll.

The existence of this special pair, or chlorophyll dimer, is implied by evidence from electron paramagnetic resonance (EPR), a variant of NMR (Figure 4). EPR measures how many molecules are acting in a coherent unit with respect to an electron excitation. Katz demonstrated that the EPR data imply that the molecular spatial extent of the photoexcited electron state in the PRC is approximately twice the size of one chlorophyll molecule. EPR is the electron magnetic equivalent of NMR, utilizing a constant external magnetic field to spin-align the electrons (compared to the spin-alignment of positively charged nuclei in NMR), and a second alternating field which, at resonant frequencies, changes the spin alignment of electrons of specific energies (that is, specific local magnetic flux densities) away from the direction of the constant field. This change of alignment occurs, as in any quantum effect, in discontinuous energy jumps of specific quantities, which are associated with energy absorption from the alternating field input at particular frequencies (the energy quantum being related to the frequency as in visible light), resulting in a characteristic absorption spectrum.

The significant finding here concerns the width of the shape of the absorption peak lines, rather than the specific frequency of the absorption maximum. The narrower the width, the larger the number of (hydrogen) protons that are closely coupling with the electron in question (see table). In the case of P700, the EPR peak is 40 percent narrower than the isolated monomer form of Chl a. This corresponds to a doubling of the absorption unit size, because quantum predictions suggest that the peak width should scale inversely with the square root of the number of molecules sharing the excited state (see box). This idea is backed up by similar spectra occurring in molecules that are built up in the laboratory by chemically bonding together two chlorophyll molecules (Figure 5).

A second variant of NMR combines NMR with EPR, resulting in electron nuclear double resonance (ENDOR) spectroscopy. Here, as in EPR, an external constant magnetic field is applied that aligns the spins of the hydrogen nuclei (protons) as well as the unpaired excited electron. Then an alternating field at the resonant frequency of the excited electron saturates (fully excites, so no more photons at the given wavelength can be absorbed) an electron absorption band. A second alternating field, however, is then introduced at the resonant frequency of the hydrogen protons. The resulting spin shift of the protons affects local magnetic flux and changes the maximum amplitude of the electron absorption (changing the saturation potential, which would allow either more or less absorption), and this can be used as a measure of the degree of coupling between the excited electron and nearby hydrogen protons. To quantify this effect, it has been demonstrated that the electron-nuclear hyperfine coupling constant for the individual monomer is N times the constant for the N-fold functional aggregate. In this case, N is found to be close to 2, varying from 1.9 to 2.2 for different classes of protons (different peaks within the overall ENDOR spectrum), (as shown in Figure 6).

Both the EPR and ENDOR results could, however, still possibly be explained by environmental effects other than

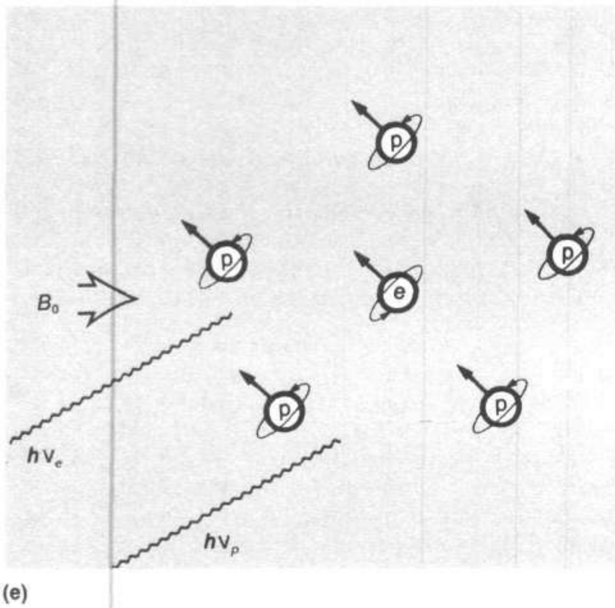


(a) (b) (c) (d)

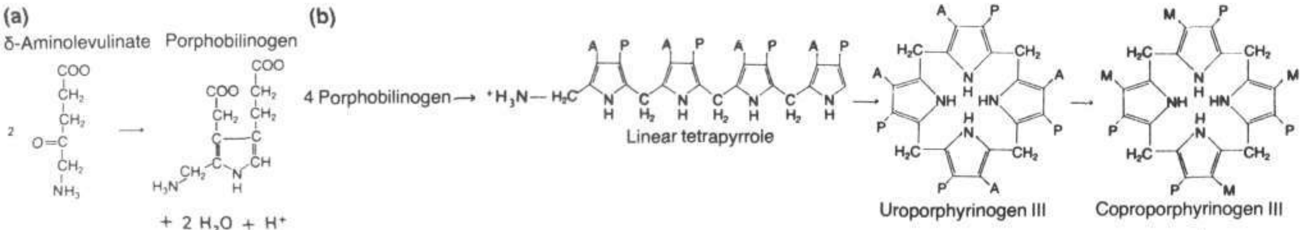
Figure 6
ENDOR SPECTROSCOPY DATA

Electron nuclear double resonance, ENDOR, is an extension of NMR and EPR. Again, we begin with a substance, whose nuclei and electrons are each spinning and creating local magnetic fields (a). An applied external magnetic field aligns the local magnetic fields of both the positively charged nuclei and the negatively charged electrons (b). Photons of the absorption frequency of the electron $h\nu_e$ *are then put into the sample, causing the electrons to reverse their magnetic poles, as in EPR, and the total amount of such photon energy that the sample can absorb is noted. The next step is to put photons of the absorption frequency of the nuclei (usually hydrogen nuclei, or protons) into the sample, energizing the nuclei (d).*

With the nuclei energized, the electrons are again energized, but because the protons have now been changed in their orientation, the energy needed to fully energize the electrons is slightly changed (e). This is termed the ENDOR effect. The size of the change gives information on how many nuclei are coupled to the electron in question, and therefore supplements, and in this case, confirms, the results of EPR in determining that PRC chlorophyll functions as two molecules of chlorophyll in one unit.



(e)



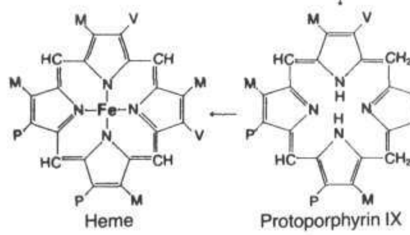


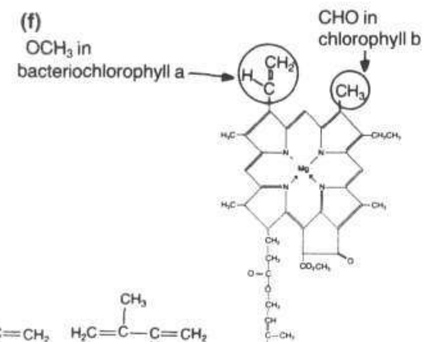
Figure 7
THE METABOLIC CONSTRUCTION OF CHLOROPHYLL

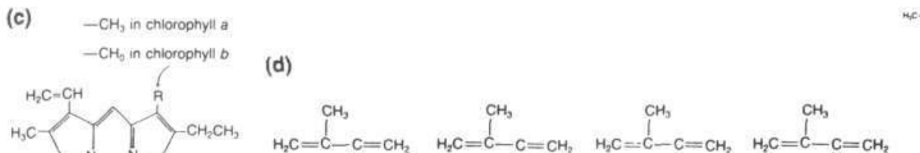
Chlorophyll is constructed metabolically in a series of orderly steps. For the large macrocycle portion, the initial building block is delta-aminolevulinate, a five-carbon chain with an amino group containing nitrogen. Two of these groups are combined asymmetrically to form a five-sided ring structure termed porphobilinogen, (a). The five-fold aspect of the construction interestingly carries through the entire synthesis. In (b), four of the pentagonal rings have been linked to form a linear chain, called linear tetrapyrrole, which is then closed into a macrocycle or larger ring, termed uroporphyrinogen III. Subsequent changes in the side chains, mostly decarboxylations, produce protoporphyrin IX. If iron is added at this point, the result is heme, a component of hemoglobin.

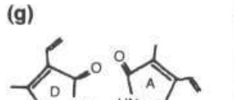
Alternatively, if the ring is further modified and magnesium is substituted for iron, a chlorophyll macrocycle results, (c). Notice that in the case of chlorophyll, a fifth pentagonal ring has been formed by linking two of the side chains, in the lower right portion of the molecule as shown. The final step is the addition to the macrocycle of the long carbon chain tail, termed the phytol tail. This tail is a chain of 20 carbons, which is formed from the building block isoprene, a five-carbon chain, (d). Four of these units add to form the phytol tail, shown in (e), which is then added to the chlorophyll macrocycle, giving the final chlorophyll molecule shown schematically in (f).

Several variations of chlorophyll exist, including chlorophyll a, b, and bacteriochlorophyll. The differences consist of changes in the side chains of the macrocycle, and the substitutions are circled in (f). In a certain sense, the five-fold character of the synthesis continues in the last steps, since there are five pentagons, and the four isoprene units that form the tail are then added to the macrocycle, which can be thought of as the fifth unit in this series of additions. The significance of this repeated five-fold symmetry may be related to the self-similar nature of any living and growing process. Self-similarity is generally characterized by the ratio of the golden mean, and the golden mean is based geometrically on the pentagon.

In (g), The chlorophyll-related compound phytochrome can be seen as closely related to linear tetrapyrrole. Phytochrome is involved with plant sensing of the presence of light for a variety of functions, such as sensing the length of day for determining the season of flowering activity. It is interesting to hypothesize that the function of light sensing, which involves a compound related to an intermediate step in the construction of chlorophyll, precedes chlorophyll also evolutionarily. The development of photosynthesis, then, would involve a geometric shift, in this case a topological change involving the closing of the macrocycle, which is involved in the change from light sensing, to the use of light as a source of work potential.







a chlorophyll special pair model, particularly since the excited electron state is presumed to "ring" the molecule and therefore is accessible to near neighbor effects. However, the nitrogens within the macrocycle ring are less exposed, and the spectrum of the nitrogens is additional evidence in favor of the special pair notion, as measured by the technique of electron spin-echo spectroscopy (ESE). This technique utilizes the secondary field effects of the relaxing or flipping back of the electron spin, which occurs in the course of usual EPR, and is particularly useful for studying the hyperfine interactions between nitrogen and excited electrons. The electron spin-echo spectroscopy pattern for P700 is radically different from P670, indicating that the primary electron-donor for ubiquinone reduction cannot be monomeric chlorophyll.

Although the usual quantum-mechanical interpretations of the above spectral experiments are frequently reductionistic in methodology, the spectra themselves are provocative and indicate that qualitative differences exist in the various forms of chlorophyll in the PTU, which the NMR-type spectral results indicate are differences in something akin to long-range phase coherence (such as in the case of the simpler NMR of "structured" water).

Quantum Upshift

The indication that photons are concentrated at the PRC prompted J.E. Hunt at Argonne to push P700 to the limit with intense laser irradiation. With nanosecond pulses in the megawatt range, he showed recently that 700 nm radiation results in 400 nm fluorescence, an upshift of almost doubling the frequency. The quantum efficiency of this under his experimental conditions was very small, 1/100,000. Hunt also showed that the hyperexcited state of the chlorophyll could reduce a dye substance whose reduction required that higher amount of energy, opening up the possibility that the Chl sp may function in this fashion in normal physiological conditions. That is, the question raised by this finding is whether such an upshift of quantum size is part of the usual functioning of chlorophyll. Such an upshift would represent a work aspect of the photosynthetic apparatus apart from the above-mentioned concentrating of photons at the PRC, and the transduction of the excited electron state to the reduction of ubiquinone.

While mean sunlight intensity is far below the laser pulse used by 10 orders of magnitude, the concentrating of photons into the reaction center by the antenna could at least partially make up for this and increase the flux. Additionally, if the directionality of photon flux is established by antenna geometry, and the Chl sp is designed to reduce ubiquinone only after receiving a second photon, then in the living state such an upshift could be the dominant mode. This is now a very hot point of debate, and workers in the area feel that this is a definite possibility. As an aside, if the in vitro PTU is irradiated with blue light at 400 nm, it will not fluoresce; it will only do so if it receives intense red light (700 nm), and then it will fluoresce in the blue. In the normally functioning state, chlorophyll does not fluoresce at all or only minimally, since most of the photons are utilized to reduce quinones for the eventual production of carbohydrates. This stands out as a strange and anomalous finding. Hyperexcited chlorophyll can also be made to lase, and should respond differently to polarized light. However, this polarization experiment, simple as it is, is yet to be done.

Thus the overall picture of the PTU that emerges is that of a photon potential trap with the Chl sp at the bottom, in which a slight change downward in spectral frequency toward the PRC, combined with an almost 100 percent efficiency of photon transfer within the PTU, results in an immense increase in photon flux at the PRC, and may very well include a sizable upshift in frequency at the PRC. If "chlorophyll" is thought of as actually a mode of self-induced transparency, the variation in characteristic absorption and emission wavelength within the PTU can be seen as a varying retarded potential, serving to perform the above described concentrating and upshifting functions.

The NMR-related data reviewed above only begin to answer the question of geometric ordering of the PTU. There are only fragmentary data concerning the relation of antenna chlorophylls among themselves and with relation to the PRC. This is one of the most difficult—and fascinating—areas for future research.

Related Processes

The porphyrin macrocycle portion of chlorophyll, with slight variations, is also involved in numerous other work transformations in the cell. The heme in hemoglobin, which is involved in oxygen transport, is almost identical, with iron substituting for magnesium. The cytochromes in the ATP-forming oxidative respiration that goes on in the mitochondria (the "powerhouses" of the cell) are protein-porphyrin enzyme complexes with stepwise varying redox potentials. Thus the metabolic construction of porphyrin represents an entire array of work functions. Likewise the simpler pyrrole compounds represent a lower array of functions. Thus the stepwise metabolic construction of chlorophyll may correspond, at each qualitative step, to historical evolutionary state of life. For example, the simpler pigments may have originally had more of a sensory function to direct the microorganism toward a pond surface for food-gathering (such as the current use of retinene in the mammalian eye which is closely related to the carotene in plants, or the plant sensory pigment phytochrome which is closely related to chlorophyll), and later evolved the photon-food conversion function (retinene, carotene, and the chlorophyll phytol tail are all constructed metabolically from the same isopentene [isoprene], with the pyrrole compounds differing topologically in being closed on themselves in loops). This would be an example of extreme physiology transformation that requires a comparatively straightforward and simple topological change in geometric (metabolic) construction (Figure 8).

The characteristic geometry involved in these construction pathways is dominated by pentagonal-golden-mean self-similar forms. Therefore, we must investigate further the role of such geometries, which, as Leonardo da Vinci first showed, characterize life more generally, in the process of evolution.

Ned Rosinsky, a physician, is on the biology staff of the Fusion Energy Foundation.

How the Space Shuttle Program Was Sabotaged

by Marsha Freeman

Although their arguments have changed over the past 25 years, the opponents of man's exploration of space have always made sure the program was underfunded.

NASA

From the greatest heights of accomplishment to the dog days of massive budget cuts, the U.S. space program has always been surrounded by individuals and institutions that have tried to stop man's exploration of space. The critics have changed their mode of attack, depending upon the circumstances and political environment in the nation, but their aim has always been the same.

Since Jan. 28, the nation's attention has been focused on the shock of the Space Shuttle Challenger loss, and the public circus of the Rogers Commission "investigation." The press, speaking for the space critics, has asked whether the Shuttle program should continue at all, whether it is safe, whether it is worth the money—ad nauseum.

Before manned exploration of space was even technologically possible, its opponents were amassing their forces. Once President John Kennedy had gone above the counsel of all of his advisers and started the race to the Moon, the focus of attack became the supposedly negative "social impact" of such a large-scale science and engineering effort.

With Kennedy gone, the assault on the space program shifted, as opponents insisted that the United States could not afford the Apollo program, because of the high cost of the Vietnam war and the poverty here on Earth. President Lyndon Johnson's Great Society replaced the Apollo project, thereby ushering in the antitechnology "paradigm shift" in the U.S. population, which has become so much more pronounced today.

The Nixon administration certainly did not buy the idea of cutting the space program to pay for more social programs, but the economic crisis of the early 1970s put the "conservative" budget-cutters firmly in charge of major policy decisions. Thanks to budget director George Shultz, "cost effectiveness" became the watchword for all federal programs—to the detriment of scientific rigor.

At the same time, the administration and Congress were being convinced by Henry Kissinger (then assistant to the President for national security affairs) and Shultz that rather than spend money on advanced technology for defense, the United States should sign the Antiballistic Missile and SALT treaties. Because the Soviets had no intention of slowing down either their offensive or defensive science-and-technology weapons programs, these treaties, plus the slowdown of the civilian space program, were to lay the basis for the current strategic superiority of the Soviets.

The same situation exists today, in that the first cuts that will be made in defense spending, under the guise of balancing the budget, will be the leading-edge laser and other technologies in the Strategic Defense Initiative programs, giving the Soviets the final superiority.

Under President Carter, "small is beautiful" became the stated policy of the White House, and the decision was made that no new large programs for space would be started, while billions of dollars would be wasted on energy conservation and "appropriate technology."

"Over 15 years of the development and first flights of the Shuttle, the wrong criteria were used in making crucial choices." Here, the Columbia orbiter making its way to the launch site.

NASA administrator James Webb: "The policy on which this budget is based is the mastery of space, and its utilization for the benefit of mankind. . . ."

NASA

Although President Reagan would like to have a space program with challenging goals and a future, he is ending up with the "Richard Nixon" approach to cost-benefit analysis and "private enterprise" for the National Aeronautics and Space Administration (NASA).

Let us be clear about the current situation. If there are safety compromises that have been made in the design and fabrication of the Space Shuttle system, or in the launch rate or other operational procedures, the blame does not fundamentally lie with the management of the space program, or its contractors. Over the 15 years of the development and first flights of the Shuttle, the wrong criteria were used in making crucial choices. When you straitjacket a research and development agency, and instruct it to build a capability spending half as much money as it should spend, you can hardly complain when it does not function according to your expectations.

When fundamental engineering considerations, like the frequency of launch, are determined not by readiness but by political pressures and the requirement to bring down the "cost" of the system, pressure is put on NASA to increase the launch rate. Combine that with a constant media campaign that has made NASA look "like a bunch of idiots who can't even handle a launch schedule," as Kennedy Space Center Director Richard Smith recently charged, and you are increasing the risk in the program, and potentially compromising safety, as senior astronaut John Young has pointed out.

The two questions facing the Congress—the elected representatives of a nation, three-quarters of whose citizens insist that they want the Shuttle program to continue—are first, whether we are willing to commit the resources to actually have the kind of Space Shuttle capability the nation requires; and second, whether we will make the same budget-balancing mistakes with the upcoming space station that was made in the Shuttle program.

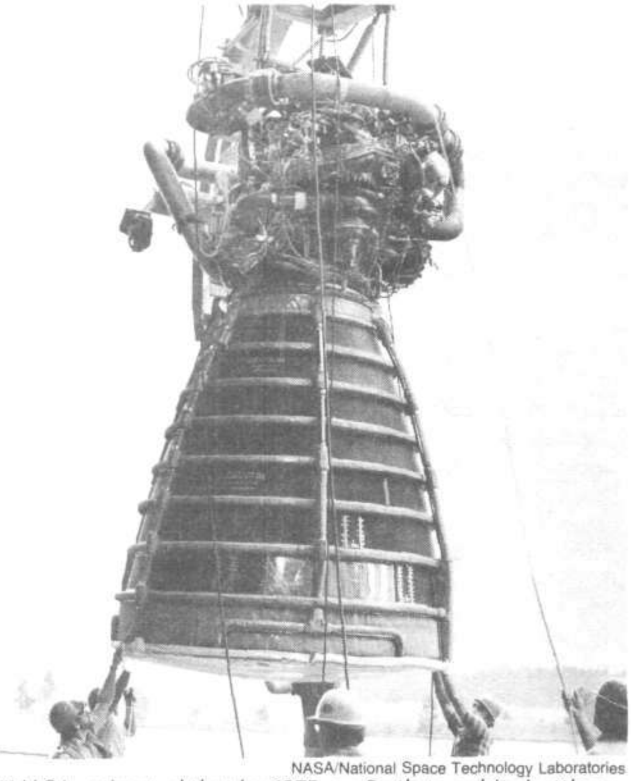
The Lost Opportunity in Space

Plans for what should follow the Apollo program, started years before astronaut Neil Armstrong took that famous first step on the Moon, July 20, 1969. By 1965, much of the hardware for the lunar voyages had already been ordered, built, and had begun testing, and NASA was ready to begin planning for the exploration of the next frontiers. By 1965, however, NASA was under a barrage of attacks from the "social" think-tanks like the Brookings Institution, the Tavistock Institute in London, and the self-proclaimed Aquarian Conspiracy (see box, page 45). President Johnson's State of the Union address Jan. 4, 1965 was the first since Sputnik (1957) that did not even mention the space program.

As the NASA budget began to decline, program planners fought to keep open the space frontier. German-American space pioneer Wernher von Braun, for example, penned articles and books on lunar colonization, the exploration of Mars, and other projects that required an Earth-orbital space station, and a shuttle-type vehicle to service it.

NASA administrator James Webb refused to operate with the notion that NASA had been created just to go to the Moon. In motivating the NASA budget request for fiscal year 1965, Webb stated:

> The policy on which this budget is based is the mastery of space, and its utilization for the benefit of mankind. This mastery and the relation of our position to those of other nations will not be determined by any single achievement.



NASA/National Space Technology Laboratories

"NASA estimated that by 1975, an Earth-to-orbit shuttle vehicle would be operational, and a year later a tug could take passengers from Earth orbit to the Moon. By 1978, a nuclear-propelled orbital transfer vehicle would be ready. All it took was the will to set NASA to work." Here, a Shuttle main engine in a test stand in 1979.

> The NASA program is designed to expand both science and technology. We have avoided a narrow program, one limited, for example, to developing only the technology needed to reach the Moon with state-of-the-art hardware. To do so might well be to find, some years hence, that we had won the battle and lost the war as far as ultimate and enduring superiority in space is concerned.

Webb made the painful decision to resign as NASA head in 1968, just months before Apollo 11 lifted off, because it had become clear that there would be no budget, and no post-Apollo plan for space. He left NASA before the occurrence of the lunar landing, for which he had prepared for seven years, rather than preside over an agency which appeared to have no future.

But when man put his first footprints on the Moon, the antiscience lobby was again shunted temporarily into the background, as it had been when Kennedy launched the Apollo program, as the imagination of the entire world was captured by this great achievement.

The Great Society crowd had been voted out of office in 1968, and a new President was preparing to bask in the glory of the upcoming Apollo lunar landing. But President Nixon was to get contradictory advice. The social programmers in the Congress, the media, and a faction in the "scientific" community, accelerated their campaigns to make sure that Apollo would mark the *end*—not the beginning—of man's exploration of space.

In February 1969, President Nixon established a Space Task Group headed by Vice President Spiro Agnew to establish goals in the post-Apollo era. The task group consisted of NASA administrator Tom Paine, Secretary of the Air Force Robert Seamans, and Presidential science advisor Lee Dubridge. Robert Mayo, who directed the Bureau of the Budget, had only an observer status. The group's report, titled, *The Post-Apollo Space Program: Directions for the Future,* was released two months after the Apollo 11 landing. It projected an exciting vision of a Mars landing before the end of the century, at the latest. The lunar landing, the authors said, was "only the beginning of the long-term exploration and use of space by man." They continued:

> We see a major role for this nation in proceeding from the initial opening of this frontier to its exploitation for the benefit of mankind, and ultimately to the opening of new regions of space to access by man.
>
> We have found questions about national priorities, about the expense of manned flight operations, about new goals in space which could be interpreted as a "crash program." Principal concern in this area relates to decisions about a manned mission to Mars. We conclude that NASA has the demonstrated organizational competence and technology base to carry out a successful program to land a man on Mars within 15 years.
>
> There are a number of precursor activities necessary before such a mission can be attempted. These activities can proceed without developments specific to a manned Mars mission—but for optimum benefit should be carried out with the Mars mission in mind. We con-

clude that a manned Mars mission should be accepted as a long-range goal for the space program.

Two of the systems that the task group suggested for space operations were a new space transportation capability and space station modules, which would utilize the new capability of commonality, reusability, and economy, the fruit of the Apollo success. These capabilities would then ensure that the manned mission to Mars could certainly be done before the end of this century.

NASA, too, was working furiously to put such forward-looking goals before the Nixon White House, after the lunar landing. Also released in September 1969 was a space agency report titled "America's Next Decades in Space." It presented four scenarios through which new space capabilities could be developed. By 1975, the United States could have a 12-man space station, it proposed, which could be expanded to house 80 people by 1980.

A station orbiting the Moon would be put into place, with the first permanent lunar surface base to be established in 1978. At the fastest pace, NASA stated that the first manned Mars expedition could be in 1981. Even if the NASA budget were limited to a ceiling of $4 billion per year, these missions could all be achieved, if a few years later.

NASA estimated that by 1975, an Earth-to-orbit shuttle vehicle would be operational, and a year later a tug could take passengers from Earth orbit to the Moon. By 1978, a nuclear-propelled orbital transfer vehicle would be ready. All it took was the will to set NASA to work.

But there was no chance that the rational deliberations of the space agency itself, or the past accomplishments of space exploration, would determine the future of the effort. Even before the task force reported its recommendations to the President, budget director George Shultz slashed the NASA 1970 budget request by $45 million!

The Office of Management and Budget (OMB) dictated to NASA, and the President, that they would have to operate with no major increases in the budget; that the OMB would have to be satisfied that "cost-effective criteria" were met before any large project could be developed; that any new program, like the Space Shuttle, would have to use as much Apollo-developed technology as possible; and that there would be no "crash" programs. Similar constraints have been made upon President Reagan's space station initiative.

On Capitol Hill, many of the cast of characters today clamoring for the dismantling of the space program, were also doing so then. Thus, Sen. Edward Kennedy (D-Mass.), speaking at the dedication of a new Goddard Library at Clark University on May 19, 1969, called for a "slowdown" of the space program. As NASA historian emeritus Eugene Emme noted, the senator's remarks were "profanity to the memory of John F. Kennedy, who had set Apollo in motion, if not also to the memory of Robert H. Goddard." The landing of Apollo 11 was just two months away.

NASA planners were determined, however, to use the giant Saturn V rocket and the Apollo technology for at least a temporary space station. Skylab was launched in 1973, and produced stunning results in space science, astronomy, biology, and materials processing. Designed for only temporary service, Skylab 1 was to be followed by a second U.S. space station. That station, Skylab 2, sits today as an exhibit in the National Air and Space Museum in Washington, D.C., never having been launched. Skylab was a larger station than the entire series of Soviet Salyut stations used for the past decade.


NASA

NASA administrator James Beggs: "When you come down to it, the bottom line is what they allow you to do in the budget. . . . With another billion dollars in the program, we would be able to do a lot of things that we or even the scientific community would like to do. We would like to see some new beginnings because this program lives by stepping up so often to something new."

Space Station: Déja Vu?

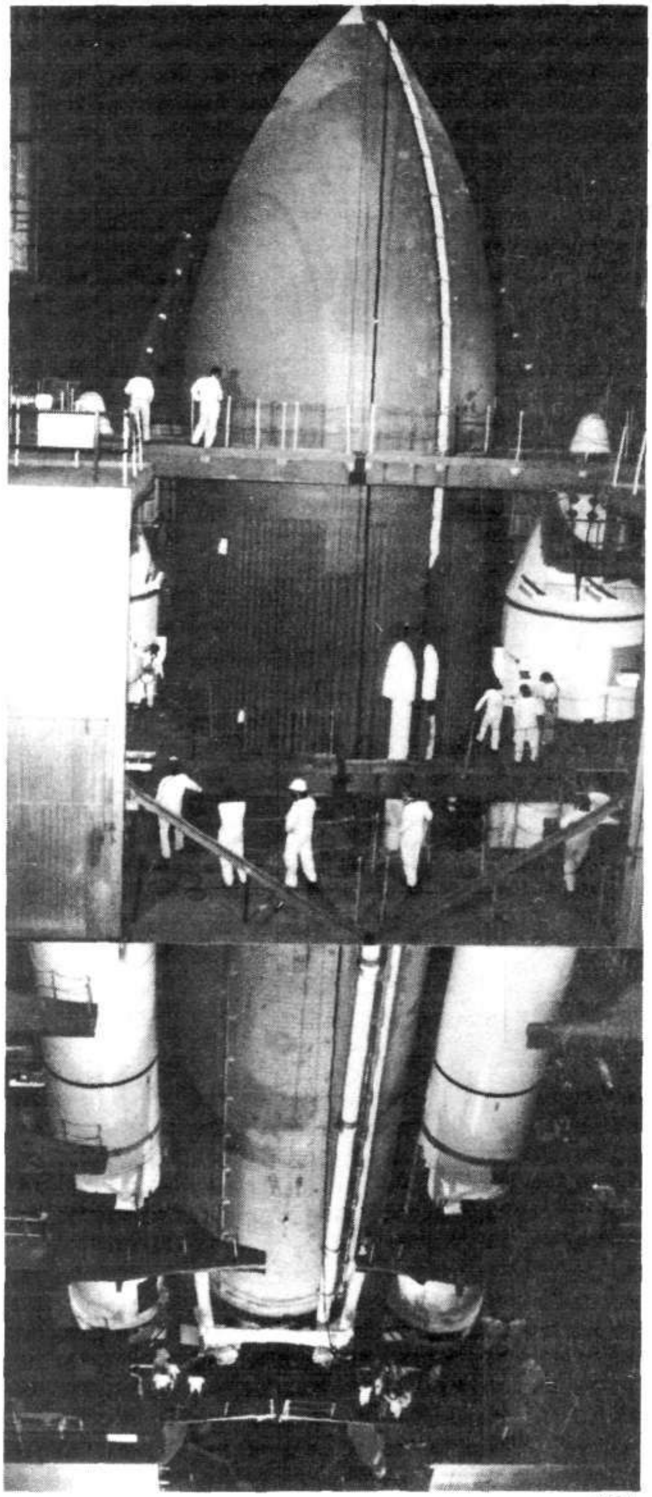
In his State of the Union address in 1984, President Reagan asked NASA to build an Earth-orbital space station that would begin operations within a decade. In a replay of the Nixon Shuttle decision, the OMB immediately cut NASA's funding request for the new initiative. Originally, the space community had hoped to bring the station on-line in 1992, for the 500th anniversary of Columbus's discovery of America. With the budget cuts in the past two years, NASA is now not even sure if it can meet even the 1994 deadline that President Reagan gave the program.

Colonel Gilbert Rye, director of space programs on the National Security Council staff, wrote in 1985: "President Reagan believes a space station can stimulate a boom in the commercial development of space, much as the railroads opened the western frontier." In September 1984, according to Rye, Reagan said, "Bringing into full play America's greatest asset—the vitality of our free enterprise system—will do more to spur the development of space for the benefit of man than any of us can now imagine."

Both Rye and President Reagan seem to have forgotten that it was only *President Lincoln's* commitment to link the transcontinental railroads that got the job done, and laid down the infrastructure for the real growth of American industry and agriculture, not some mystical "free enterprise."

Former NASA Administrator James Beggs stated a different view of the importance of the space station project in 1985:

> A space station is the logical expansion of our activities into space. Indeed, a look back at the origins of


NASA

"To cut the cost of the Shuttle in half, of course, design compromises had to be made. Instead of being boosted on a reusable first stage, the Shuttle would have two partially reusable boosters at its side." Here, the huge external tank is surrounded by engineers and technicians while being mated to the solid rocket boosters at Kennedy Space Center in April 1982.

our planning for the Space Transportation System shows that we had two things in mind. One was efficient, routine, and economical transportation into space with the Shuttle.

The other was a space station to provide a continuous manned presence in orbit. While the Shuttle allows us to do many new things in space, it is not an end in itself. Rather, it is an enabling mechanism toward other ends, which together with a space station, will promote broad-reaching expansion of the space program over the next century and beyond.

In 1975, former NASA head Tom Paine, "one of the most innovative thinkers," according to Beggs, laid out a 100-year scenario, that included the Space Shuttle and Spacelab; an Earth-orbital station, then moving the space station capability further out to geosynchronous orbit; then a lunar orbiting station, a lunar colony; and then a station and colony on Mars. These are the reasons to build a space station.

In an interview in *Sky and Telescope* magazine, on the occasion of the 25th anniversary of the space age, Beggs stated:

> When you come down to it, the bottom line is what they allow you to do in the budget. What I would like to see during the period I occupy this chair is the establishment of a policy and precedent that says the country will continue to do research and technology development on a long-term basis, at a level commensurate with the benefits that we receive from the program.
>
> . . .With another billion dollars in the program, we would be able to do a lot of things that we or even the scientific community would like to do. We would like to see some new beginnings because this program lives by stepping up so often to something new. That's what keeps our people thinking, creating.

Years with No Vision

By 1978, it was becoming clear that the underfunding of the program, which led to cutbacks in testing of key components and replacing tests with cheaper computer simulations, plus the difficulty of the technologies themselves, meant that NASA either would have to ask the Congress for more money, or would never complete the development of the Shuttle. As the program schedule slipped further behind, the NASA leadership refrained from an aggressive lobbying effort to get more money, fearing that the entire project might be scrapped.

But in 1978, President Carter was persuaded that the Shuttle was needed to verify any violations of the SALT II treaty. Former astronaut Harrison Schmitt recalled: "I was serving in the Senate at that time, and it became clear to me, and to others, that the day of reckoning had come for the early underfunding of the Shuttle program." Frank Press, Carter's Presidential science adviser, (now head of the National Academy of Sciences) and NASA head Robert Frosch made clear that NASA would get no budget relief, no planned fifth orbiter, and no new space project during their tenure.

That the frontal assault was against NASA, and *not* simply against all federal spending, can be seen in the accompanying table. While social welfare and "soft" technology boondoggles were growing by leaps and bounds, NASA's budget increased by a mere 4 percent, between 1967 and 1980. It would have had to increase by 147 percent, just to keep up with inflation. It is indeed amazing that NASA was able to build the Shuttle at all.

Though federal aid to higher education began skyrocketing in the early 1970s, the peak year for the graduation of new physicists was 1969, close to the NASA peak funding year. All of the billions of dollars in federal aid to education has never produced as many scientists and engineers as NASA did.

The same is true for developing new energy technologies. NASA-supported projects throughout the 1960s in advanced nuclear technologies for propulsion, new energy conversion techniques such as magnetohydrodynamics, and other programs contributed more to the nation's energy R&D than the billions of dollars spent on solar energy by Carter's Department of Energy.

Speaking at the annual conference of the American Astronautical Society in 1982, Darrell Branscome, then staff director of the House Subcommittee on Space Science and Applications, stated: "Inflation has had a significant impact on NASA spending power. Whereas in 1982 the actual dollar amounts are increased slightly above the 1966 funding level, in terms of purchasing power, the current NASA budget is less than one-third the 1966 level." Former NASA head James Beggs has repeatedly made the same point.

Some have charged that President Carter's interest in the space program stemmed from his report in 1969 that he had seen a UFO. Be that as it may, look at his niggardly approach to space exploration, as conveyed in an October 1978 speech at the Kennedy Space Center:

> We have invested some $100 billion over the history of our American space program. It is now time to capitalize on that major investment.
>
> The first great era of the space age is over. The second is about to begin. It will come into its own with the new space shuttle, the heart of our new Space Transportation System, when it becomes operational. Paradoxically, the most exciting thing about the space shuttle is that it will make our use of space in the future routine and perhaps not very exciting.

Carter described his policy as the "evolution of our space program from exploration to operations."

Speaking for the Carter National Security Council, General Robert Rosenberg stated that since the Shuttle will be less expensive, the "freed funds and talent can be applied to important space efforts we cannot afford today." Shuttle optimization and increases in productivity, he said, "perhaps can only be found through forced fiscal restraint."

NASA began to bring the Shuttle into the public eye with the aerodynamic tests of the prototype orbiter Enterprise during the Ford administration. Finally, the agency had "something to show for the money." But the advent of the Reagan presidency in 1981 did not change the direction of the Shuttle program—it merely rationalized the miserly approach toward space that the previous administrations had instituted.

Budget Increases for Various Federal Government Agencies (1967-1980)

NASA	4%
Transportation	193%
Education	344%
Energy	888%
Income security	481%
Health	685%

The 'Cost-Effective' Shuttle

When Dr. James Fletcher came in to head NASA in May 1971, it had become very clear that the space agency would wangle only one new manned space program out of the Nixon White House. Since there was little point in having a space station without a transportation system to get astronauts there and back, NASA opted to build the Space Shuttle, or Space Transportation System. Of course, not everyone agreed that the Shuttle was necessary. Senators Walter Mondale, William Proxmire, Clifford Case, and Jacob Javits continued their opposition to any new manned space initiative. The Budget Office was unconvinced that it was a good "investment."

According to space historian John Logsdon, unlike the Apollo initiative, the Shuttle was arrived at through a three-year negotiating and compromise process, rather than from a Presidential mandate. He has described this as "pluralistic policymaking." It was also the first space program analyzed in terms of cost effectiveness.

One factor that increased the cost of the Shuttle by an estimated 20 percent is that the military did not want the kind of quick and small transport-to-orbit capability that NASA had first envisioned; it wanted a large vehicle that could accomplish military missions outside the scope of its available expendable launch vehicles. This greatly increased the size of the orbiter NASA designed. The sensible programmatic approach would have been to develop a stable of launch vehicles, including a reusable Shuttle and a heavy-lift expendable vehicle, that could carry military payloads comparable to the lunar-Saturn V. But, no money was available to pursue the parallel development of these next-generation systems.

President Nixon stated in his budget message Feb. 2, 1970 that he had "received many exciting alternatives for the future. Consistent with other national priorities, we shall seek to extend our capabilities—both manned and unmanned." Behind the scenes, however, warfare against the space program was being conducted by George Shultz at the OMB and White House staffer Peter Flannagan, a representative of Wall Street's Dillon Reed.

NASA had proposed to build a fully reusable two-stage Shuttle system, where the first-stage manned booster would separate from the orbiter before reaching orbit, and fly back to Earth to be reused. The Shuttle would continue on up to orbit, using its own engines. NASA head Fletcher recognized that he would have to sell this to the White House, and that the only effective argument would be that the Shuttle would be cheaper per pound of payload launched than the available expendable rockets. He awarded a $600,000 study contract to Mathematica, Inc. to study the economics of the Shuttle program.

The study showed that with a *fully reusable* Shuttle, costing about $12.8 billion for its development, savings of about $100 million would accrue, compared to the use of expendables. The determining factor in cost was shown to be the number of operational flights. It was thus clear from the beginning that if the major proof of the viability of the system were to be its "economics," the number of flights would be key.

Fletcher knew that NASA would have to develop this system within a fixed budget, a peak funding level of $2 billion, with a projected development time of six years. There was no way NASA would be allowed to spend $12 billion. He sent Mathematica back to the drawing board, and the company did an analysis based on the cheaper, one-stage, not fully reusable design. Meanwhile, the OMB had told Fletcher that he would probably end up with about *half* of the $12 billion.

The mission model was a highly optimistic one, showing a two-week turnaround time for the orbiters and sufficient flights to make it "economical" enough to sell to the Budget Office. NASA ended up with a $5.2 billion total development price, a 1978 flight start, and a 20 percent limit on cost overruns. According to the antiscience *New York Times*, "NASA left itself no margin for error. This is the classic engineer's nightmare."

To cut the cost of the Shuttle in half, of course, design compromises had to be made. Instead of being boosted on a reusable first stage, the Shuttle would have two partially reusable boosters at its side. To increase the payload capability, the fuel tank would be external to the orbiter and expendable. Both these decisions would have a negative impact on the overall safety of the system.

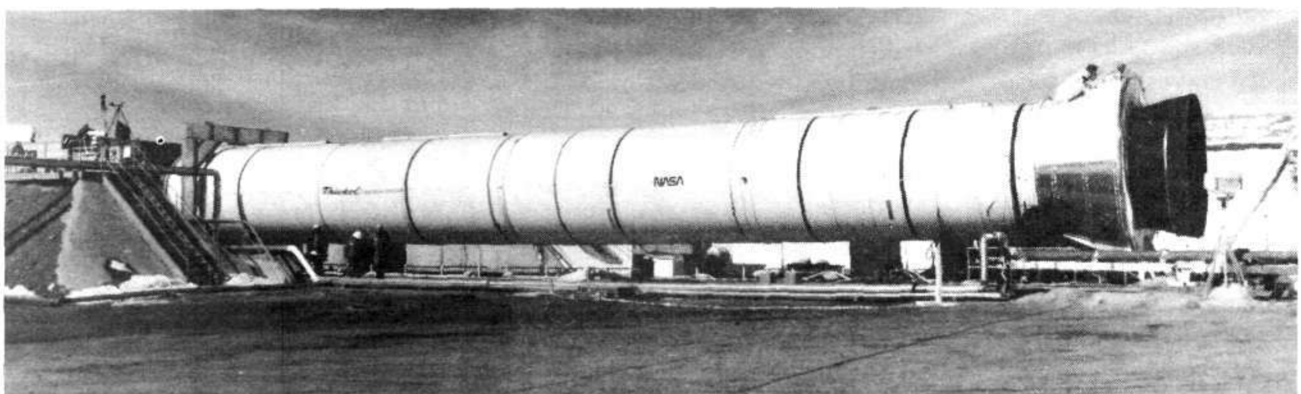
The debate on final Shuttle design continued until days before Nixon announced the program, on Jan. 5, 1972. He declared that the Shuttle "will revolutionize transportation into near space, by routinizing it. In short, it will go a long way toward delivering the rich benefits of practical space utilization and the valuable spinoffs from space efforts into the daily lives of Americans and all people." Noting that "1972 is a year of conclusion for America's current series of manned flights to the Moon," Nixon described the Shuttle as being used up to 100 times per vehicle, which would bring operating costs down as low as one-tenth those of present launch vehicles.

On March 15 that same year, NASA announced that it had decided to opt for solid-fueled boosters instead of liquid-fueled boosters, because of lower cost and lower technical risk, since this was a proven technology. Solid-fueled boosters had been used for years on expendable rockets, but never before in a manned spacecraft system.

The contract for the boosters went to Morton Thiokol. The location of their production plant in Utah meant that the 149-foot-long boosters had to be shipped in segments, in order to be transported safely. This created the requirement that the boosters had to be stacked together at the Kennedy Space Center. Questions about the joints between these segments have been raised during the investigation of the Challenger explosion.

Within weeks of Nixon's announcement, the NASA budget was cut by nearly *half a billion dollars*. The projected Shuttle launch date slipped from 1978 to 1979, and the process of underfunding the next NASA manned space program was off and running. If President Nixon's Space Shuttle was off to a bad start, President Reagan's space station is faring no better.

NASA has estimated it will cost at least $700 million just to replace the equipment lost in the January explosion (excluding a replacement orbiter), pay for the investigation and salvage operations, make the modifications the Rogers Commission might recommend, and store the payloads that were ready for launch until the Shuttle starts flying again. A replacement orbiter will cost about $2 billion and take more than three years to complete and test. The Congressional Budget Office released a report earlier in March saying that all of this is certainly too much money. The report states that money could be taken from the space



Thiokol Corporation

"NASA announced that it had decided to opt for solid-fueled boosters instead of liquid-fueled boosters, because of lower cost and lower technical risk, since this was a proven technology." Here, one of the Shuttle booster motors is tested at Thiokol's Wasatch Division in Utah in 1979.

Who Wants to Stop Manned Space Exploration?

As early as President Kennedy's 1961 announcement of the Apollo program, think-tanks like the London-based Tavistock Institute and the Washington-based Brookings Institution warned that the space program was driving America in the dangerous direction of "technological and cultural optimism." At the same time, the fledgling antiscience environmentalist movement pitted the space program against the needs of the poor and pollution. NASA was under continuous assault. Here are a few of the leading spokesmen who set out, under various pretexts, to prevent man from exploring space.

Barry Commoner, *The Nation*, Dec. 16, 1962.

Other undertakings are more important than space. At this moment, in some other city, a group may be meeting to consider how to provide air for the first human inhabitants on the Moon. Yet, we are meeting here because we have not yet learned how to manage our lives without fouling the air man must continue to breathe on Mother Earth.

Tavistock Institute, *Human Relations*, 1966.

The space program is producing an extraordinary number of "redundant" and "supernumerary" scientists and engineers. "There would soon be two scientists for every man, woman, and dog in the society."

Tavistock Institute, *Social Indicators*, 1966.

Measures of social performance are all the more important in a "postindustrial" society, one in which the satisfaction of human interests and values has at least as high a priority as the pursuit of economic goals. . . . The Great Society looks beyond the prospects of abundance to the problems of abundance.

Father Theodore Hesburgh, S.J., Council on Foreign Relations, Trilateral Commission, president of Notre Dame, November 1962.

The preoccupation of scientists with space and military research is prostituting science to something far below its capacity for abolishing disease, hunger, and illiteracy on a worldwide basis. Should we pioneer in space and be timid on Earth and leave man in bondage below?

Senator J. William Fulbright, *Washington Post*, May 5, 1963.

Fulbright said that he found it "strange" that "in a world which bears an intolerable burden of hunger, disease, poverty and animosity among its people, we should devote so many of the best minds of both Western and Communist worlds to achieve a landing on the Moon, where, to my knowledge, no solutions to our problems await us."

Senator William Proxmire, Aug. 20, 1962.

I think there is great waste in this program. This latest single increase in the space budget will result in a tax of $70 for every American family—of all of our 50 million American families—for the nondefense program. I wonder if most people approve of spending at that rate for this kind of program.

Brookings Institution, *Proposed Studies of the Implications of Peaceful Space Activities for Human Affairs*, March 1961.

The exploration of space requires vast investments of money, men and materials and creative effort—investments which could be profitably applied also to other areas of human endeavor, and which may not be so applied if space activities overly attract the available resources.

New York Times, John Finney, April 7, 1963.

With the appreciation of the cost have come questions as to whether the space agency needs so much money and whether some of the funds could not be spent more profitably on Earth or even not be spent at all.

Dr. Philip Abelson, American Association of the Club of Rome, editor of *Science*, April 19, 1963.

NASA has sought examples of technology fallout in its program. To date, those cited have not been impressive. The problems of space are different from the earthly taxpaying economy. . . . I believe the program may delay conquests of cancer and mental illness.

Newsweek, Sept. 30, 1968

Now as NASA draws close to the time when it either fails or fulfills that commitment [to land on the Moon] the U.S. space program is in decline. The Vietnam war and the desperate conditions of the nation's poor and its cities—which make spaceflight seem, in comparison, like an embarrassing national self-indulgence—have combined to drag down a program where the sky was no longer the limit.

station program, which won't be built on time without a full orbiter fleet anyway, and from the development of new science experiment payloads, which won't be able to fly.

Will the Lesson Be Learned?

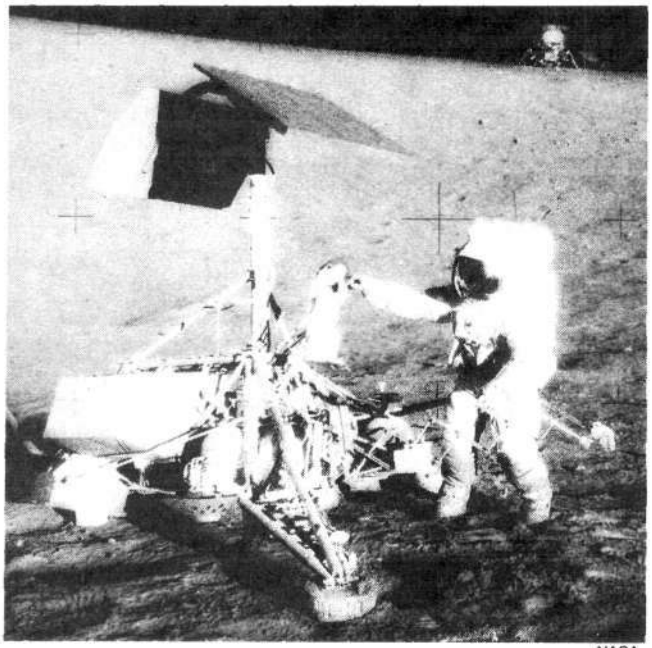
This country has a fundamental decision to make. Cuts in operating costs, maintenance, training, and pay through the deregulation of the commercial airlines, in 1985 produced a year with more fatalities than any other in the history of flight. Space Shuttle accidents are, of course, more spectacular and shocking than airline crashes, but the causes are not that much different. No matter what the investigating bodies may finally determine the cause of the Challenger explosion to be—even if it was sabotage—we have, as a nation, paid for the 15 years of cheating the space program.

By fiscal year 1974, the NASA budget of $2.9 billion was the lowest it had been since 1963. According to NASA historian Emme, "Later cuts, though less severe, reduced confidence even in the 1979 date, which undoubtedly had some impact on schedule delays in 1978-80. Although President Nixon (and subsequently President Ford) continued to support the Shuttle Program in principle, the budgetary process with its cuts did not allow the orderly development that the Apollo Program had enjoyed."

Speaking before the National Academy of Engineering in November 1975, NASA head Fletcher stated: "The OMB, which controls the government's pursestrings, rarely plans beyond one or two years at a time. NASA's Space Shuttle program is an excellent example of the effects of year-to-year budget cycles. The program has never been funded in its entirety, but has been piecemealed together out of the agency's overall yearly budget. Yet, if NASA did not proceed with the development of the Shuttle, the nation would be without a major new space program for the 1980s."

That commitment to the interest of the nation, despite the most unworkable constraints and demands on the space agency, was reflected recently by former Apollo astronaut Harrison Schmitt. In a commentary written two days after the Challenger loss, Schmitt stated:

> In sharp contrast to Apollo, the early years in the design and development of the Space Shuttle were played out in a far more constrained fiscal environment. . . .
>
> There were many of us "old Apollo heads" who, on detailed exposure in 1973 to the near-final concepts for the Space Shuttle, felt that the new program was underfunded by a factor of three or four. [The Space Shuttle orbiter] was itself an extraordinary technical challenge. It would require more than just state-of-the-art engineering to take a spacecraft as big as a DC-9 into orbit, make good use of it in the harsh environment of space, fly it on return through hypersonic ranges never before experienced by aircraft, land it on a standard airport runway, and then recycle it for reuse within a few weeks.
>
> Those of us who were skeptical about NASA's ability to succeed in this endeavor were wrong. We underestimated, as so many have, the unexcelled motivation and heart of the NASA family. Space and space flight generate a belief in hundreds of thousands of Americans that working on the exploration of this new ocean is the most important endeavor of their lives.



NASA

"Those who would try to force the space program to justify itself in return-on-investment statistics are either fools, or are out to cripple mankind's most valuable undertaking." Here, astronaut Charles Conrad, Jr. examines the Surveyor III spacecraft on the surface of the Moon.

NASA persevered, trying to build a leading-edge Shuttle system without enough money. NASA also realized that the Shuttle would be the only manned space capability that the United States would have for nearly two decades. The agency built into the Shuttle the ability to spend 7 to 10 days in space, so scientific experiments in the European-built Spacelab could be done in orbit, since there would be no space station. The Shuttle was no longer simply a "truck" to haul cargo to Earth orbit or to a space station; it became a major space facility on its own.

Budget Constraints and Safety

Were there any red-flag warning signals that the Space Shuttle system was being stretched to its limit, before the loss of the Challenger? Absolutely.

The Aerospace Safety Advisory Panel, which is independent of NASA, recently released its annual report for 1985. It contains a frontal attack on the stated Space Shuttle policy of the Reagan administration, which for the past three years has been to make the system "operational and cost effective." The panel objects that neither of those goals is coherent with maintaining safety as the primary responsibility of the space agency, and warns NASA that budget constraints will continue to compromise the safety of the system.

One part of the report gave NASA the opportunity to respond to statements made in the report from the year before. The panel had recommended that the NASA management "would be well advised to avoid advertising the Shuttle as being 'operational' in the airlines sense when it clearly isn't. . . . Shuttle operations for the next five to ten years are not likely to achieve the 'routine' characteristics associated with commercial airline operations. Given this reality, the continuing use of the term 'operational' simply compounds the unique management challenge of guiding the STS through this period of 'development' evaluation."

All that NASA could do to respond was to quote directly from National Security Decision Directive 42, which is the stated policy for the space program by the White House:

> NASA's highest priority is to make the Nation's Space Transportation System operational and cost-effective in providing routine access to space. Fully operational means that the STS is ready and available for routine use in the intended operational environment to achieve the committed operational objective. This means that . . . adequate logistics support for the systems is in place; that the ground and flight processing capabilities are adequate to support the committed flight schedule of up to 24 flights per year with margins for routine contingencies attendant with a flight surge capability. Cost effective means that the Shuttle provides space services for specific levels of mission capabilities with an efficiency at least equivalent to the cost of alternate systems.

It has always been the case that the major parameter that determines the cost of launches is the flight rate. Safety is not mentioned in the directive.

As soon as the Shuttle started flying in April 1981, the Heritage Foundation, a Washington, D.C. "conservative" think-tank (whose views are actually similar to Soviet policy for the United States), suggested that it may be time to consider abandoning the Shuttle program as too costly, particularly if the number of flights turned out to be "less than needed to generate sufficient revenues."

The report of the Aerospace Safety Advisory Panel states that the "attainment of NASA's goal of 24 launches per year will challenge the capacities of both the physical and human resources" of the agency. The report points to the following facts:

1) "A number of flight hardware components are still undergoing development for both performance and reliability." That is, this is by no means a fully operational system.

2) Additional "brick and mortar" facilities are required at the Kennedy Space Center "for orbiter processing and component maintenance." Without these facilities, it is not possible for NASA to turn the orbiters around in a decreasing amount of time. The alternative is to try to keep to the launch schedule without doing all the work on the Shuttles that is required.

3) "There are ultimate limitations of human resources to compensate for shortfalls in the physcial resources (even with extraordinary dedication and effort)."

4) "Sufficient logistics support, in both hardware and systems, lies sometime in the future."

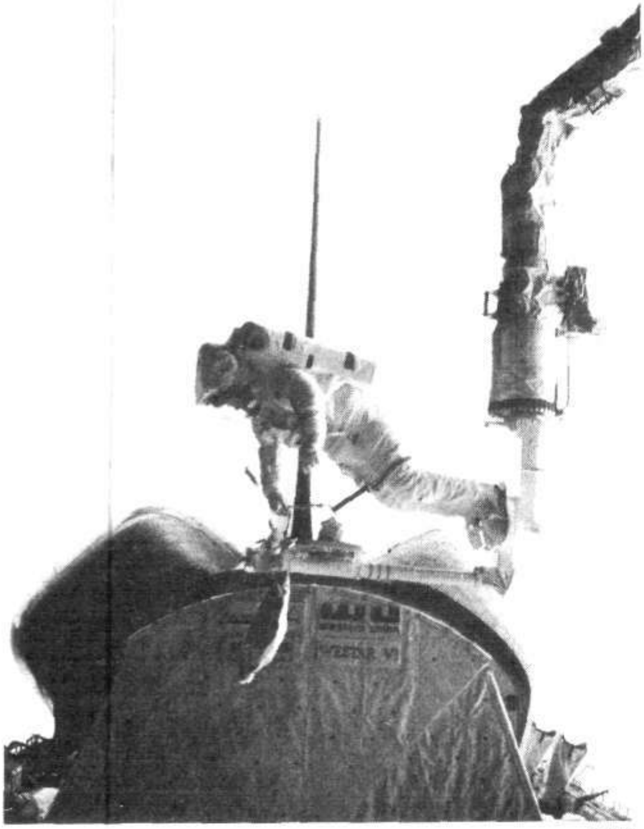
5) The fact is "that all of the above are subject to constraints by budgetary allocations."

The panel goes into detail on some of the results of the continual funding limitations. Regarding crew training, mentioned by senior astronaut John Young in his recent memo: "Time available in the present fleet of orbiter flight simulator aircraft is becoming marginal and can be foreseen as being inadequate to meet future training demands." The panel recommends that "NASA commit the funds in a timely manner to ensure an adequately sized fleet of training aircraft." This problem only gets worse, as the number of missions and therefore, number of required trained crews, increases with launch frequency.

In 1983, the panel reports, a three-phase program was initiated to substantially improve the Space Shuttle Main Engines. "However, as a result of severe funding-rate limitations, the program was restructured in 1984 to address only certain improvements to the wear life of various turbopump components," the report states.

In the crucial, and much criticized, area of spare parts, which are needed to be able to maintain a higher launch rate with safe vehicles, the panel states:

> [The] entire program is being "restructured to comply with budget restraints. A significant element of this restructuring is the use of planned cannibalization," from other orbiters.



NASA

Astronaut Bruce McCandless II tests a "cherry picker" type device during a February 1984 Shuttle flight.

Today cannibalization is a prime means by which many spares are provided, STS orbiter 103 [Atlantis] has been a major "spare parts bin," but what crisis will develop in six months when these units are needed for the first flight out of Vandenberg [Air Force Base in California]? There has to be a minimum allocation of spare units to permit the planned number of of flights.

Reducing the allocation of spares to fit the budget is going at the problem backwards . . . realistic planning should be accomplished to establish the number of missions that can realistically be flown based on such curtailments. The number of missions should be based on real capability.

Expressing further concerns about flight rate, the panel states that the existing constraints include hardware, spares, needed modifications, and payload manifesting (preparation) difficulties. "The goal of 18 flights per year is not within reach at present," they conclude. "A more realistic goal is between 12 and 15 flights per year."

Despite President Reagan's manifest enthusiasm for the space program, in the final analysis, he has merely continued the policy of sabotaging America's space initiative, by starving it of the funds that were critically necessary to allow it to keep functioning, much less allow it to expand. Whatever the immediate cause of the Challenger disaster finally proves to be, the seeds of disaster were laid by the years of underfunding and the series of policy decisions that sabotaged the Space Shuttle program from its inception.

Marsha Freeman is director of industrial engineering for the Fusion Energy Foundation.

The Real Economics of NASA's Space Program

The effect of space exploration on the economy, as with any great project, can never be judged simply in terms of the project's immediate, or even long-term economic payback, because also reaped are both the technological spinoffs hitting many other projects and industries, and the technological optimism that lays the basis for conquering new frontiers. Whole generations of mankind have been transformed by the accomplishment embodied in Brunelleschi's dome on the cathedral in Renaissance Florence, for example, or by the great internal improvements programs inaugurated in the 19th-century United States, particularly under Abraham Lincoln.

The scientists and engineers graduated and trained for the Apollo lunar landing, like those who came through the training of Admiral Rickover's nuclear navy, have fanned throughout society to make breakthroughs that have given us the artificial heart, new energy sources, and so forth.

Even had President Kennedy's Apollo program failed to achieve its goals, falling short of a landing on the Moon, the technical manpower and the technological developments accrued from having taken up that challenge would have made it more than worthwhile.

From the ability to operate in orbit above the Earth, mankind gained the capability to survey his planet continuously from space. If the remote-sensing capabilities developed in the Apollo program were actually applied on a large scale, agriculturalists could intervene internationally to prevent large-scale destruction of food from floods, drought, pestilence, and disease.

From orbit, it is possible to bring even the remotest village into contact with the rest of the world, through the use of communications satellites and small Earth-based antennas. Planning new development projects, where the careful mapping of rivers, geological formations, and other natural features is key, can only be done efficiently from space.

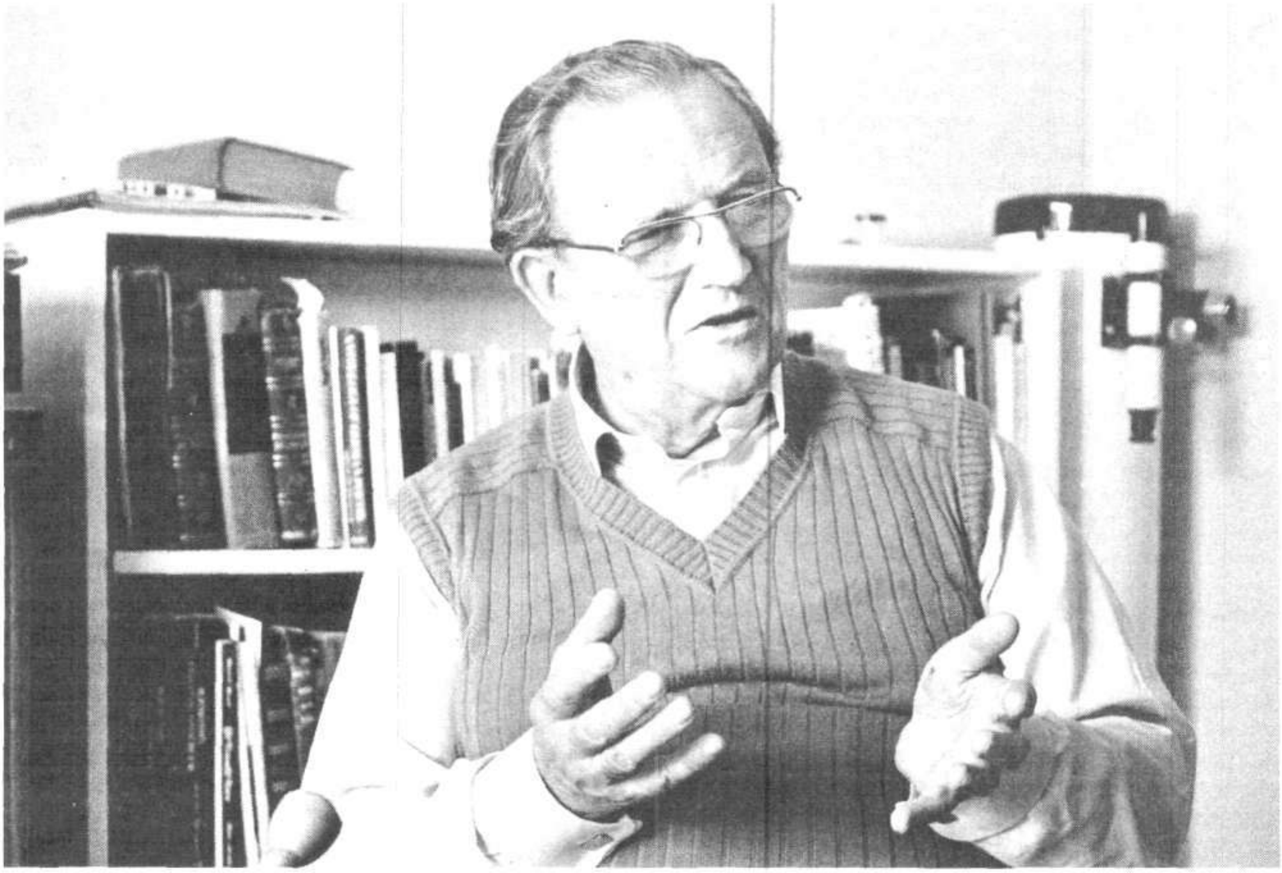
Technologies such as advanced solar cells, which had to be developed for space application, have brought rural communities in India their first bit of electricity—to run a refrigerator, a radio, and a reading light.

Nearly every piece of equipment in today's intensive care units in hospitals was developed when doctors had to be able to monitor the health of astronauts thousands of miles from Earth. It is very likely that tomorrow's breakthroughs in genetic engineering or cancer will be significantly influenced by the problems NASA will have to solve in sending the first human beings millions of miles away, to Mars.

Experiments being performed aboard the Space Shuttle now are producing ultrapure biological materials that hold out the hope of curing, not simply treating, chronic diseases such as hemophilia and diabetes.

It is not really possible to turn into dollars what the space program has bought for the world community over its 25-year history. Those who would try to force the space program to justify itself in return-on-investment statistics are either fools, or are out to cripple mankind's most valuable undertaking.

50 Years As a Physicist In Germany



Stuart K. Lewis

Professor Erich Bagge during an August 1985 seminar with the Fusion Energy Foundation staff.

A Memoir by Prof. Erich Bagge

The father of the West German nuclear program discusses his studies with Sommerfield and Heisenberg and the early German work on nuclear energy.

EDITOR'S NOTE

We are happy to present this memoir by the father of the West German nuclear program, Dr. Erich Bagge, now professor emeritus of physics at the Christian Albrecht University in Kiel. Bagge visited the Fusion Energy Foundation headquarters in August 1985 to give a seminar on his thesis that the neutrino is a fiction and his alternative theory and experimental work on how electrons and positrons came into existence. This memoir grew out of many discussions during his U.S. visit, which we thought that readers would find as fascinating as we did. From his training as a student of two extraordinary physicists—Arnold Sommerfeld and Werner Heisenberg—to his development of the West German nuclear-propelled ship Otto Hahn, *Bagge's memoir provides a unique view of classical German science before, during, and after World War II.*

This was translated from the German by Jerry Hyman.

When you asked me how I became interested in physics, there is a simple answer: I am the son of a locksmith and machinist who owned his own small factory, which produced simple agricultural implements such as harrows and turnip cutters, as well as makeshift equipment for the puppetmakers in my home town. Although it was not at all clear at that time that I would go into physics, I was very interested in technical problems, such as how motors or radios (just coming into being during my youth) worked. As a high schooler, I had to work in my father's business, helping assemble larger machines, which we got from other companies in order to resell them.

So it was easy for me to understand physics when I got to high school, because this has so much to do with technology. Since I had just as little difficulty with mathematics, it seemed certain that after my final examinations I would go into math or physics; this required a formal application, which I submitted. I was turned down by the Bavarian Cultural Ministry, although I had the best grades in all scientific subjects. For whatever reason, I was not the right man for them. There certainly was a reason, though, which I found consoling: My native state of Coburg had been part of Bavaria only since 1920; in 1931, when I applied, we Coburgers were politically and administratively integrated, but we were still not real Bavarians.

So I decided to study physics in its technical applications at the Munich Technical Institute. My special interest was mechanics, and at that time that was synonymous with Ludwig Föppl, the son of August Föppl, who wrote the famous six-volume *Mechanics*. Hearing the younger Föppl, and then reading his father's great work, was sheer joy. Just about the same time—really the hour following Föppl's lectures, which were from 10:15 to 11—I attended the famous atomic physicist Arnold Sommerfeld's great introductory lectures in theoretical physics. These were just as fascinating as Föppl's lectures—the latter because of their fascinating technical applications, which always came up for discussion along with pure theory; and the former for their groundbreaking significance for all of physics. Both, however, were superb in their clarity and the compactness of their presentation. These were great times for teaching physics at the Munich Technical Institute.

Nonetheless, my studies were focused on completing the exam for a diploma in technical physics as fast as possible. My parents, who were paying for my education, insisted on it.

I was also interested in seeing what was going on at other schools, so in 1933 I went to Berlin for a year. On an earlier visit to Berlin for a physics colloquium, I had seen Einstein, as well as Max von Laue and Walter H. Nernst, and had been deeply influenced by them. This time I had the great fortune to attend Erwin Schrödinger's last two Berlin lectures. These extremely interesting lectures were on wave mechanics, a field founded by Schrödinger. I eagerly took notes and sought to understand these lectures. I also attended mathematician Erhard Schmidt's excellent lectures on partial differential equations, and von Rothe's lectures on differential geometry. Both subjects were of great help to my further studies.

First Experiments

Returning to Munich in 1934, I joined Professor H. Kulenkampff's group in the physics department at the Munich Technical Institute. At that time they were working on the problem of cosmic rays. They were concerned with the question of how these rays from outer space could penetrate the entire atmosphere, since it was assumed that they were either high-energy quantum rays or electrons. The newly developed quantum electrodynamics held that neither of these could possibly penetrate Earth's atmosphere, which has a mass equivalent to a layer of water 10 meters thick. Thus, a kind of working hypothesis was developed which said that these rays were transformed, on their way through the atmosphere, into a mass-bearing but charge-free particle. These neutral particles could traverse vast stretches of the atmosphere unhindered by the air, until they reached the Earth's surface.

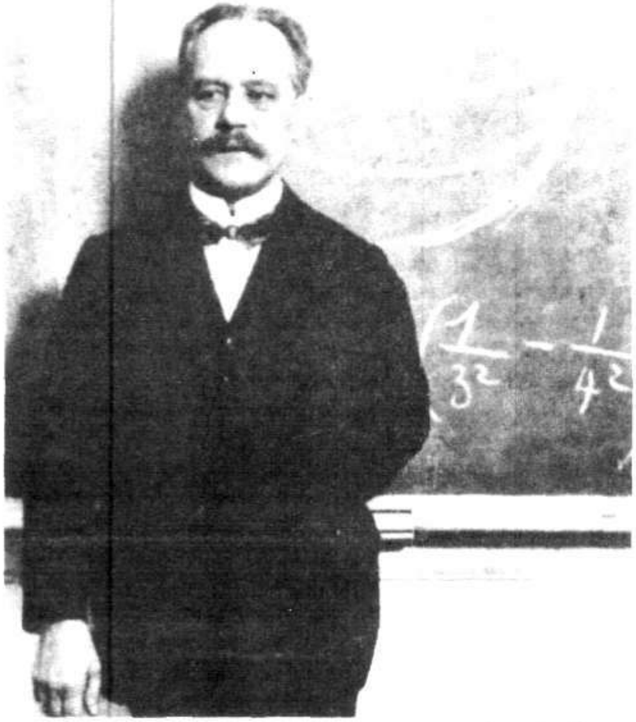
My assignment was to investigate whether such transformation into particles could be observed in lead. I used a homemade Geiger counter and a new amplifier that had been developed by Joseph Goubeau, a colleague of Kulenkampff. My observations went on for several months and gave a clear answer: no. I would like to think this contributed to Kulenkampff's discovery two years later of the first true reason for the great penetrating power of cosmic rays.

After striking the atmosphere, protons, which make up most of the particles in cosmic rays, are dislodged. These particles, because of their greater mass, are not slowed down as much as electrons, and thus can easily penetrate the atmosphere. This hypothetical explanation was subsequently proven correct.

These experiments got me my diploma, and I was free to devote myself to theoretical physics. That very same day I went to Sommerfeld and asked him if he would be my advisor in a doctoral program. His answer rang out: "Of course, Bagge, of course." He knew me from exercises I had done in connection with his lectures, and besides I had discussed with him my ideas on the origin of cosmic rays. It was enjoyable to discuss new concepts with Sommerfeld, because he related to young students as a concerned father to a son. If someone came to him with a half-baked idea, he was never rude; he listened quietly, and then, grinning, he would propose another idea and say, "Well, what do you think of this?"

So he knew me well, but especially from one particular event. He assigned me to his thermodynamics lecture of about 100 students, which was due the next week, and it seemed very hard. I can't remember exactly what the question was. One had to find two paths to the same solution, one starting from a singularity, the other from a standpoint of continuity. If the problem was calculated exactly, both solutions should give the same result. All this was announced when the assignment was given.

I got down to work and struggled all week long to crack this hard nut. I was on the verge of despair, when finally, on the last day, I succeeded in getting both solutions to work out to the same result. I handed in my work just in time, and it was announced at the next class that I was the only one who had gotten the right answer. So I had certainly won a place in the heart of my highly esteemed teacher, Sommerfeld.



University of Stuttgart

Physicist Arnold Sommerfeld (1868-1951). Bagge attended his introductory lectures in theoretical physics at the Munich Technical Institute.

This was the background as Sommerfeld continued to answer my request for doctoral candidacy, after his spontaneous assent. "You shouldn't do it," he said. "You see, I am 68 years old, and I'm retiring in six weeks. My successor will be Werner Heisenberg, who was my doctoral student. You'll lose half a year if you start with me. Go to Leipzig where you can start right away with Heisenberg."

Before I could say a word, he sat down at his desk and wrote out a short letter, which he handed to me in an unsealed envelope. "Dear Heisenberg," the letter began, "There is a young man here named Bagge, whom I know very well. He would lose half a year if he began his doctoral work with me, so I'm sending him to you."

So the whole thing was wrapped up as quickly as that, and a few days later, Nov. 5, 1935, I found myself on the express to Leipzig.

With Heisenberg

My first visit with Heisenberg was just about as brief as my last visit with Sommerfeld. Naturally, he wanted to know what I had studied in physics so far. He was especially interested to hear that I had conducted experiments on cosmic rays, and he commented, "If you want to matriculate

Werner Heisenberg (left), his assistant Hans Euler (second from right), and student colleagues at the Institute for Theoretical Physics of the University of Leipzig, taking a rest while hiking the Erzgebirge in 1938. Bagge is in the back row at left.

Courtesy of Erich Bagge

here, you'll have to learn more. Listen to my lectures, come to our seminar, and give me a presentation. We'll talk about your work later."

I attended my first lecture in Leipzig in November 1935, and it was about atomic physics. This field was both new and interesting. Heisenberg had just taken on a new student, Hans Euler, who had carried out calculations on the lighter nuclei, those with the same number of protons and neutrons. Heisenberg was interested in generalizing Euler's theory to deal with the case of the heavier nuclei in which there are more neutrons than protons. It was certain that the calculations had been simplified because of the symmetrical properties of the lighter nuclei. It was hoped that, by studying the heavier nuclei, our knowledge of nuclear forces would be increased. This was my assignment.

It soon became apparent that this involved the solution of more than 2,000 individual integrals, without a single false calculation. This took a great deal of time, patience, and strong nerves. As we were finishing up this work, a visitor reported to us on some exciting cosmic ray experiments being conducted by two physicists in Vienna, Marietta Blau and Henriette Wambacher. In 1937, they put some photographic plates in unmanned balloons and sent them up to very high altitudes. The plates were then recovered and developed, with some very surprising results. Next to the traces of the individual protons of cosmic rays, there was evidence of exploding nuclei of silver atoms, though this was not yet obvious to us.

This effect, caused by the high-energy particles of cosmic rays, showed the physical peculiarity that such nuclear explosions were "damping down" charged particles. These "damped" particles showed noticeably less energy than one would expect in the nucleus of a silver atom.

Since I had just been intensively involved with heavy nuclei, it all became clear to me a few days later how the existence of these relatively energy-poor particles could be explained. In many ways, an atom behaves like a fluid drop. When it meets a high-energy nucleon, it begins to oscillate. The oscillation deforms the radius of the nucleus, causing certain particles to be at a greater distance from the center. From there, certain particles could be knocked out, which would pick up still less energy in light of the Coulomb field of the otherwise diminished peak of the accompanying potential wall.

The theory of oscillating water drops had been developed in the last century by the English physicist Lord John Rayleigh. It depends on the interaction of the inertia and surface tension of the fluid. The theory needs only the addition of the interaction of the electrical charge of the protons, in order to give a good description of the atomic nucleus.

I gave my report on this at the German physics convention at Breslau on May 30, 1938, and while I was there, two thought-provoking incidents occurred. When I went to lunch after giving my report, the well-known physicist Walter Schottky, an expert in semiconductors, called me over to his table. He got right to the point: "Your report was very interesting theoretically," he said, "but will nuclear physics ever have any practical use? I've been looking at this problem myself the last few weeks, and no matter how hard I look, I can't find any nuclear process with a practical effect greater than 10^{-5}. It looks bad for any technical use for our knowledge of nuclear physics."

I could only agree with him. Exactly six months and 20 days later, a letter was dropped in a mailbox in Berlin-Dahlem. This letter was from Otto Hahn and was sent to the magazine *Naturwissenschaft*. It announced the discovery of uranium fission by Hahn and Fritz Strassmann, and it unleashed the century's greatest technological revolution.

The entire conversation with Schottky, this awe-inspiring and distinguished Nestor of physics, left this young beginner somewhat discouraged. He ended with the friendly advice, "Bagge, go into something else."

Right after this, while I was still eating lunch, three strangers approached me and said they had heard my lecture. They then cautiously asked if I'd be willing to come work for the War Ministry, as an experimenter in nuclear physics. I was guaranteed my freedom as a theoretician. I explained to them that I was perfectly happy at Heisenberg's Leipzig Institute, and I would like to stay there. So

Courtesy of Erich Bagge

Left: Werner Heisenberg in summer 1943 at the Berlin-Wannsee suburban station, near a branch of the Kaiser Wilhelm Institute for Physics. Right: Every worker gets half an apple from the institute garden, even the boss!

we said our good-byes.

It was certainly a remarkable coincidence, these three events. First, the report on the results of my research, then the frustrating discussion with Schottky, and finally, a job offer in a ministry. My ambition, however, was to continue work in theoretical physics, and to stay at a university.

At this time, Heisenberg ran into personal difficulties; these, however, in no way affected his work or interfered with his research. Heisenberg and Hund had vigorously protested the 1933 dismissal of Jewish professors and outstanding scientists from Leipzig University. Both professors had good friends who were notable physicists of Jewish origin, men such as Niels Bohr and Wolfgang Pauli. In addition, Heisenberg and Hund jointly conducted a seminar that invited outstanding physicists from all over the world, and these guests, along with the German participants, were always received as friends. They took part in the research activities, and their participation was very fruitful.

Unfortunately this brought about a political struggle against him, sometimes in the open and sometimes secretly. His appointment to Munich was revoked, although the Munich faculty wanted him to come there. His indisputably great scientific achievements, especially his founding of quantum mechanics and the international recognition he got from winning the Nobel Prize, enabled him to withstand the attack until the end. He was able to remain active as a researcher with a large following in Germany throughout the difficult times of the war.

Nuclear Physics During World War II

On Sept. 1, 1939, the invasion of Poland began, which became the Second World War. On Sept. 8, I got my draft notice, ordering me to Berlin. With no suspicion of what was to occur, I packed my bag like any other soldier-to-be: toothbrush, razor, underwear, and so forth, and headed for the capital. I reported as ordered to the building at Hardenbergerstrasse 11. There I found myself in the War Ministry with the very same people who, a year ago in Breslau, had invited me to come with them.

"Toss your bag in the corner there," they said. "You won't be needing it. You are to organize a meeting of all the physicists in Germany who have been working on nuclear physics. You are to discuss at this meeting the technical applications of nuclear energy. The meeting is to take place on Sept. 26."

These people were, of course, aware of Hahn's and Strassmann's December 1938 discovery. On April 24, 1939, the ministry had gotten a letter from Paul Harteck, a professor of physical chemistry at Hamburg University, pointing out that uranium fission made possible the production of an explosive with unusual power. The June 19, 1939 issue of *Naturwissenschaften* carried a longer article entitled "Can the Energy Content of Atomic Nuclei Be Technically Utilized?" written by theoretician Dr. S. Flügge of the Kaiser Wilhelm Institute for Chemistry in Berlin (which is also where Hahn was). This article very plainly called attention to the possibility of freeing the energy of the nucleus. To dramatically illustrate his point, he ended his article with the statement that one gram of uranium would yield enough energy to lift a cubic kilometer of water 27 kilometers high. The article contained a number of essential fundamentals concerning making the extraction of nuclear energy a reality. Even the diffusion equation for the spatial distribution of neutrons in a "uranium machine"—as we called nuclear reactors at that time in Germany—can be found in Flügge's observations. The officers at the army weapons office had read all this, of course.

The outbreak of war gave these people a straightforward and convenient opportunity to summon the appropriate experts to Berlin. My assignment, together with physicist Dr. K. Diebner of the army weapons office, was to prepare the agenda and invite the participants to the first meeting on Sept. 26, 1939. In addition to Otto Hahn of Berlin and Paul Harteck of Hamburg, we summoned Peter Hoffmann of Leipzig, W. Bothe of Heidelberg, and Hans Geiger, J. Mattauch, and S. Flügge, all of Berlin, to the War Ministry. I felt out of place, a youngster surrounded by well-known researchers and institute directors. So I asked Dr. Diebner to invite my teacher Heisenberg, who had already given lectures in Leipzig on nuclear physics and neutron diffusion. But Heisenberg informed me that he had already discussed the matter with Hoffmann and Bothe, and they were all of the opinion, "What do you need a theoretician for? It's just a practical problem." So they weren't invited. I invited Heisenberg to the second meeting in October, and on Nov. 26 I made my recommendations for the complete list of participants.

The meeting began with a speech by Diebner's superior, senior government counselor Dr. Basche. After some introductory remarks on the war situation, Basche drew attention to Flügge's article in *Naturwissenschaften*, and stated that the task of those present was to do all the necessary work to make a final determination on the feasibility of harnessing nuclear energy. A positive answer would, of course, be very desirable, since this would mean opening up a new source of energy, which would very likely have military significance. But a negative finding would be just as important, since then one could be sure that the enemy would not have nuclear energy either.

The discussion that ensued showed that the spirited Dr. Harteck had brought some concrete ideas to the meeting. He had reflected on the arrangement of uranium and a moderator necessary to produce energy, and decided that the two should be separated so that the faster fission neutrons could be slowed down outside the uranium, from whence they could return to the fission fuel as slower particles, unleashing new fission reactions. It was already clear to him at this first meeting that heavy water was by far the best moderator for such energy-producing reactions.

At that time, we were still uncertain which of the two types of uranium nuclei, U-235 or U-238, would be fissionable. Otto Hahn was of the opinion that it would be U-235, but it was not until a year later that this question got a definitive answer. The American physicist Alfred Nier had constructed an isotope separation apparatus, and was able to show that only U-235 nuclei were fissionable with slow neutrons. We learned of this when it was published in the journal *Physical Review*.

Some of the participants were hesitant about producing energy from nuclear fission. Suddenly, Geiger, the inventor of the Geiger counter, stood up and spoke loudly, "Gentlemen, if there is just the slightest chance that this harnessing of the energy of uranium that we've been discussing here is possible, then we must start doing the necessary work."

Geiger spoke very passionately, and the gathering was obviously deeply influenced by him. No one contradicted him. After this, we began to form working groups and divided up responsibilities.

The next item was procuring uranium metal and heavy water. We bought all the heavy water that was available from the Norsk Hydro Works in Norway. Later, when German troops occupied Norway, there was not a drop of this costly fluid left. Professor Joliot-Curie of Paris had bought it all and packed it off to France; and from there it found its way first to England, and later to the United States. In 1939, however, we had available to us in Germany about a hundred liters of heavy water and a few hundred kilograms of uranium metal.

Despite diminishing resources, on Feb. 26, 1942, Heisenberg and Döpel in Leipzig succeeded in building a prototype reactor. This reactor had globular-shaped alternating layers of uranium and heavy water, and it proved that such an arrangement could produce a self-sustaining reaction (and thereby energy) if only it were large enough. The propagation factor k_∞ for the next generation of neutrons is given by:

$$k_\infty = 1.01 \pm 0.01$$

$k_\infty > 1$ signifies that when such an arrangement reached critical mass (dimension), the number of neutrons would increase from generation to generation by a factor of k_∞.

These results of Heisenberg and Döpel really proved for the first time that energy could be gotten out of uranium. The two researchers announced this on Feb. 26, 1942 in Berlin at a conference of invited guests. In his presentation before the representatives of the War Ministry and the Wehrmacht, Heisenberg stated that several tons of uranium and heavy water would be needed to make the reaction self-sustaining. An army general in attendance then asked him if he thought he would be in a position within nine months to develop a weapon that could decide the war. Heisenberg answered truthfully, "No, that is totally impossible," and Bothe of Heidelberg confirmed this statement.

A number of participants came away from this meeting thinking that a continued crash program was no longer so urgent, since the war had to come to an end within nine months. So it was decided that the powerful army weapons office would withdraw from nuclear energy research, and less influential research agencies would take its place. From this time, the work went on at a much lower priority. Our circle spoke of it as a "first-class state funeral."

Despite this, we achieved one of our previously set goals, which was raising the productive capacity of the Norwegian heavy water factory. This important material was produced at the rate of about 100 liters per month, up until the bombardment of the factory, and its total destruction by acts of sabotage in the fall of 1943. At the end of 1943 we had available to us in Germany about 2 tons of D_2O and we were able to construct large experimental devices. One such experiment, constructed in Gottow near Berlin under Dr. Diebner's direction, achieved a propagation factor of $k_\infty = 1.13 \pm 0.01$ by the end of 1943. Another experiment by Heisenberg in Haigerloch, Württemberg, operated under somewhat different conditions, and used 2 tons of uranium and 2 tons of heavy water. It achieved $k_\infty = 1.08 \pm 0.01$. There could no longer be any doubt that the realization of a chain reaction was possible. Analysis of neutron propagation measurements in the Haigerloch device showed that 75 percent of critical mass needed for a reactor had already been achieved. Another half ton of D_2O and half ton of uranium would make the Haigerloch "uranium machine" self-sustaining. In fact, even the same amount of material that we had, if it had been constructed with a spherical arrangement, would have already reached the critical point. Because of wartime conditions, the machine had been built with a cylindrical shape, which wasted neutrons. During my postwar period of internment, I calculated that if we had arranged the material in a spherically symmetrical fashion, but maintained the same internal construction, we would have reached a chain reaction. The closing days of the war prevented us from taking this last step. We had no idea at that time that a chain reaction had already been achieved, by Enrico Fermi's uranium-graphite pile in Chicago on Dec. 2, 1942.

The Internment Period

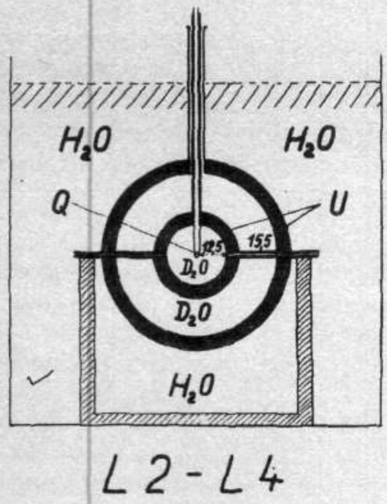
The boundary between the American and French occupation zones at that time ran to the north of Haigerloch, but the Americans attacked toward Haigerloch anyway, occupied the town for six days, and then pulled out. They took all the heavy water available, and the 2 tons of uranium. They also took Otto Hahn, Max von Laue, Karl Wirtz, Korsching, and myself with them. Hahn was the discoverer of uranium fission, von Laue was the acting director of the Kaiser Wilhelm Institute, Wirtz was Heisenberg's assistant in reactor research, and Korsching and I had devised and tested a new procedure for isotope separation. My "isotope sluice" that had been built in nearby Hechingen was dismantled and shipped to America.

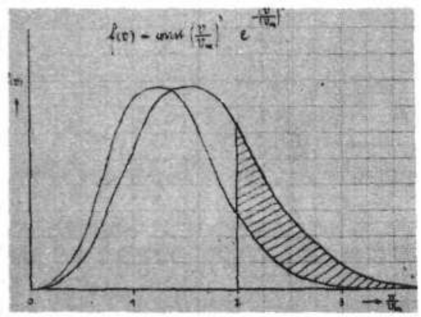
At the beginning of 1940, I had proposed a special procedure for separating isotopes. The mixture to be separated would be sent through a system of two disks rotating on an axle. The disks would have staggered apertures. At a given temperature, the vapor of the lighter isotope (in the case of uranium, the U-235) would be faster than the vapor of the heavier isotope. More of the lighter nuclei would be able to penetrate the system of apertures, and this separation effect could be utilized to separate isotopes.

Laboratory tests of the procedure in 1941, using the silver isotopes ^{107}Ag and ^{109}Ag, produced the theoretically predicted results, so we had a Berlin manufacturer build a larger apparatus in 1942. It was ready for operation when the entire factory, including all my equipment, was destroyed by bombing. The same thing happened at a subsidiary of the same company in Oberhessen. Only on the third try did we get a workable experimental device, which we set up in Hechingen during the last months of the war, where we were able to perform some crude tests.

The machine was dismantled on April 2, 1945, and we were interned, not by the Americans, but "At the pleasure of His Majesty, George VI of Britain." We scientists were taken from Hechingen to Heidelberg, and then a few days later to Reims, France. We were still in Reims when the German generals came there to sign the surrender May 8.

After that, we were held for 11 months at the pleasure of his majesty. We were joined by other scientists, Gerlach of Munich, Harteck, Heisenberg, von Weizsäcker from Strassburg, and Diebner. In the next two months, we were moved from Reims to Chesny near Versailles, from there to Le Vesinet near Paris, and then finally to Facqueval Castle near Huy, Belgium. It was obvious that we were being moved around so often to cover our tracks, to prevent anyone from knowing where we were. We were totally cut off from our

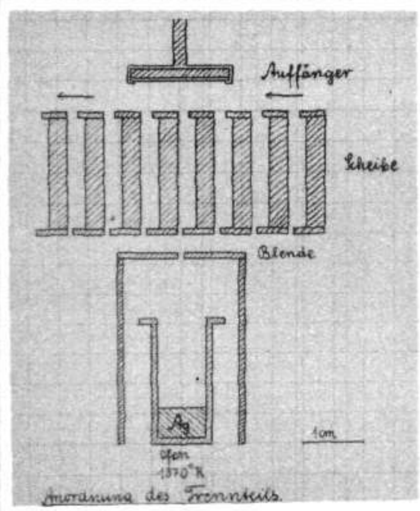


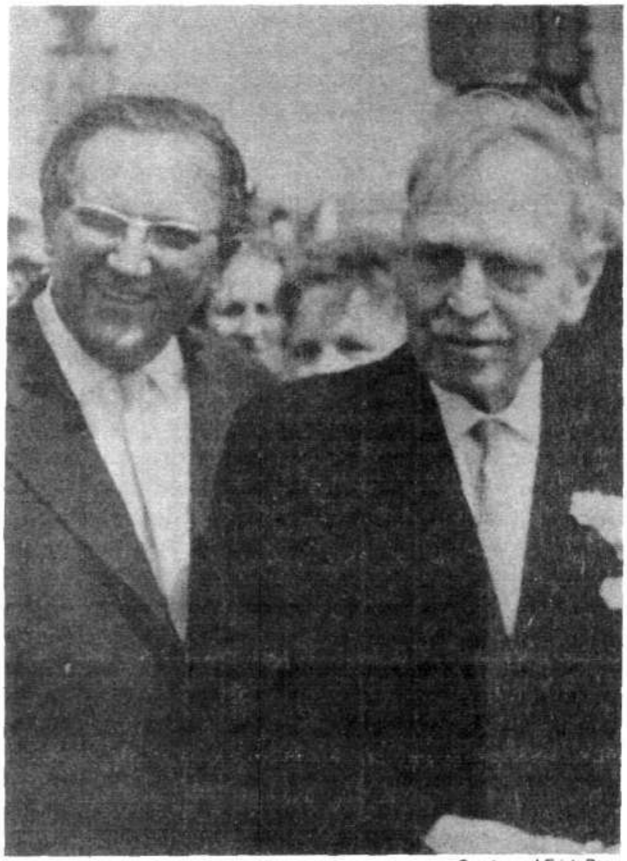


Courtesy of Erich Bagge

The construction of the Leipzig experiments L2 through L4 in 1941-1942. Heisenberg and Döpel obtained $k_\infty = 1.01 \pm 0.01$ *with L4 on Feb. 26, 1942.*

Design of Bagge's apparatus for the isotope sluice. The collector is above, the vaporizing oven below, and the two diaphragm systems are shown at center, moving from left to right.




Courtesy of Erich Bagge

Otto Hahn (right) with Erich Bagge at the launching of the nuclear ship Otto Hahn *in Kiel, June 13, 1964.*

families until the end of 1945. We were not allowed contact with anyone.

We were flown to Huntingdon, England, on July 3, 1945, where we were held for exactly six months, to the minute. We were quartered in a large home with spacious gardens, both surrounded by a wall two meters high. The six-month internment period has a special significance. In England the medieval Habeas Corpus Act is still in effect; it states that no one can be held at his majesty's pleasure for more than six months, without charges being filed. For reasons of secrecy, the English didn't want to bring us before a court, so on Jan. 3, 1946, one hour before our six months ran out, we were flown back to Germany, where we were held until March 19 in Alswede, near Minden, Westfalen. Our conditions of internment there were somewhat less stringent.

Back in Germany

After our discharge from Alswede, all of the former members of the Kaiser Wilhelm Society moved to Göttingen, with English help. There we were to form a new scientific institute, just as we had had before the war. In the course of our discussions with the occupation authorities, we learned that General Lucius Clay, the governor of the American zone, did not like the name of the old institute. So we agreed upon a new name, the Max Planck Society. The president of the new institute was Otto Hahn.

One of the first acts of the new society was to form an Institute for Physics under Heisenberg's direction. Because of the controlling laws, they were not allowed to have anything to do with nuclear energy. The next best thing was to study cosmic rays, which are supplied by outer space, at no cost, and at energies achievable in the laboratory only with accelerators. So we set ourselves to our new tasks, and I continued in this work at the University of Hamburg, where I had obtained a position in the fall of 1949. I was directing a project there, at the Hanseatic State Institute for Physics, following up on one of my ideas, with the first electronically controlled spark chamber, which allowed us to accurately measure the position, and, with several such devices, the paths, of particles within cosmic rays. Today, such measuring devices are installed on all large accelerators.

The Construction of the *Otto Hahn*

The victorious powers returned sovereignty to the Federal Republic of Germany on May 5, 1955; we could now carry out research and development in the field of nuclear energy. A year earlier, the success of the American submarine *Nautilus* became known, and was much discussed in the docks and shipyards of Hamburg. The sub had submerged in the Atlantic, traveled under the north polar ice cap, and surfaced in the Pacific near Japan. That was a great sensation for the population of northern Germany, who are so much concerned with shipbuilding and shipping. On the anniversary of the Hamburg Shipbuilding Technology Association in 1954, I was invited to give a comprehensive report on everything I could gather from the American technical literature concerning the possibility of nuclear propulsion for ships.

It was obvious to the shipping interests that this new propulsion technology would one day be of great importance not only for military purposes but also for civilian shipping. These interests gave their full support to the Society for the Study of the Use of Nuclear Energy in Shipbuilding and Shipping (KEST), founded in Hamburg on May 13, 1955. Their task was above all one of educating the population and promoting the idea of nuclear ships. On the other hand, a subsidiary organization (GKSS) was formed in April 1956 to carry out research and development (R&D) work for the construction of a nuclear ship, and to develop the necessary staff. I was chosen as the scientific and technical director. KEST had raised our start-up capital of 3.3 million deutschemarks from the private sector.

I was invited to the Geneva Conference on the Peaceful Uses of Nuclear Energy, which took place Sept. 1-15, 1955, and this proved of great use for our work. The conference was a training course in nuclear technology, and it helped us avoid many mistakes in our planning and in our R&D, since we had available to us the valuable experience of the U.S., the Soviet Union, Canada, England, and France. It became known in Geneva that it was possible to acquire research reactors from the United States, and we made use of this in 1956 with the purchase of a "swimming pool reactor." In the meantime, we had bought the 75 hectare site of the bombed-out Alfred Nobel AG works in Geesthacht, near Hamburg. This is where the inventor of dynamite first mass-produced the explosive a century ago, after he had been prohibited from doing so in his own country. We

Courtesy of Erich Bagge

The launching of the Otto Hahn. *The ship is being christened by one of the men seen at the bow.*

thought that implementing our ship reactor plans on such an historic site imposed a great obligation on us, even though our goals were so different than those of Nobel.

The Geesthacht research reactor began operating on Oct. 28, 1958, and the following years saw countless tests of materials under irradiation, and research to optimize the radiation shielding of the reactor. It became feasible to bring other German, and even foreign, industrial firms into the research work. The Euratom authorities in Brussels found this desirable. The planning work for the ship took place in close collaboration with the Howaldt Werken shipyards in Kiel. The development and the construction of the ship's reactor saw the constant cooperation of the Interatom firm in Bensberg with the GKSS. GKSS eventually employed 700 people.

We tested a number of different moderator fluids, including some organic substances, but we finally decided on the old standby of water as a coolant and moderator. We decided on a reactor type that was a cross between a pressurized water and a boiling water reactor. In the reactor vessel's radioactive steam chamber, there is plumbing that produces nonradioactive steam to drive the turbines. This compact design also proved to be the most resistant to heavy seas, although this wasn't our original reason for choosing it. The reactor had to operate in the stormy North Sea. Movements of the sea would cause random changes in the reaction, and it would be critical that the control rods promptly respond to any changes. This would be very dangerous with other reactor types. Reactor tests of this type were of course only possible by means of theoretical calculations, but they all showed that the theoretical capabilities of the reactor satisfied the practical requirements.

The ship was delivered and launched in Kiel on June 13, 1964, and was christened the *Otto Hahn* in honor of the discoverer of uranium fission. On Oct. 11, 1968, 200 guests from the worlds of politics and business were on board for her maiden voyage on the Baltic Sea. The ship continued to operate on its first load of fuel until 1972. After an overhaul and the installation of a more technologically advanced reactor core, the ship logged 580,000 nautical miles, the equivalent of 25 trips around the globe, until it was decommissioned in 1979. It had visited more than 30 different ports in 22 countries, while consuming about 20 kilograms of U-235 as fuel. The ship had a double role to play, both as a research vessel, and also as a bulk goods carrier. Because of this, as well as its size (15,000 tons), it should not have been expected to be commercially competitive. It would have had to have been about five times larger for that. Operation costs, after the two-year start-up phase, were about 3.5 million deutschemarks per year, while freight charges brought in less than half that amount. The importance of the *Otto Hahn* was as a research ship and also as a demonstration to the world of the efficiency of German nuclear technology. It completely fulfilled all that it had been intended for at the founding of GKSS in Hamburg in 1956. The ship is now having its nuclear materials unloaded, and is being decontaminated, although that is scarcely necessary since there is no discernible radioactivity. After that, it will return to sea, in somewhat different form, as a diesel-propelled ship.

The Young Scientist

National Archives

The Los Angeles, *built by the Zeppelin Company in Germany for the U.S. Navy and delivered in 1924. It flew until 1932, when congressional budget cuts made it necessary to decommission it. The Navy's experience with the* Los Angeles *and with the American-built* Shenandoah *led to the design of a long-range airship for strategic scouting with the Pacific Fleet. The two U.S. long-range scouts, the* Akron *and the* Macon, *crashed in storms in 1933 and 1935.*

A NEW DIRIGIBLE FOR HEAVY LIFT

Why Dirigibles Disappeared and How We Might Bring Them Back

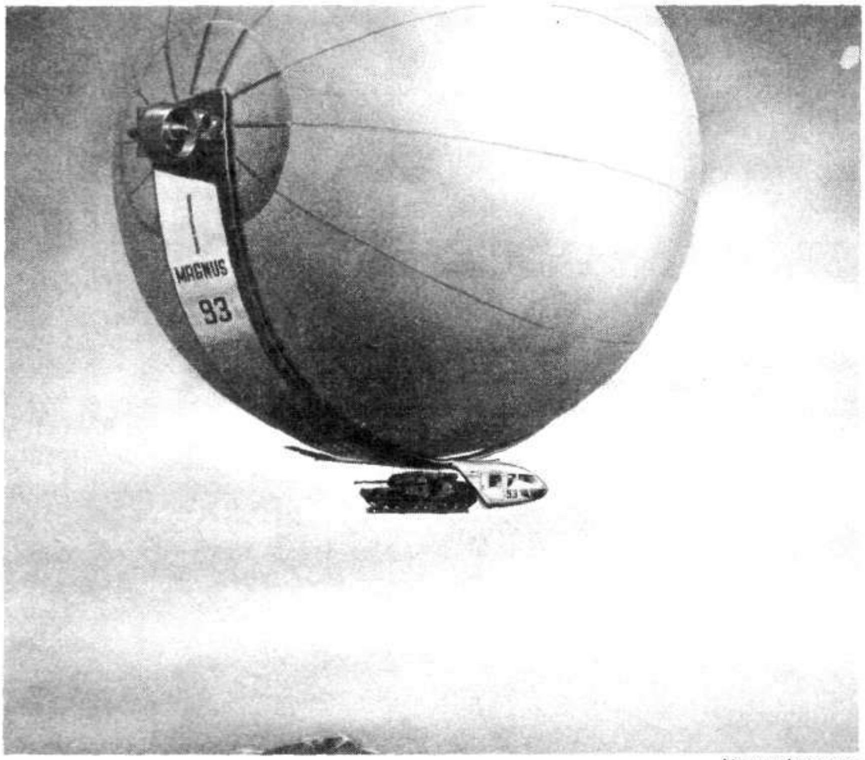
by David Cherry

When the airplane was still a dream, experimenters were taking flight in balloons filled with hot air or hydrogen. By the time the Wright brothers were achieving success with the airplane in the first years of this century, Count Ferdinand von Zeppelin in Germany was building dirigibles for passenger flights and military purposes, especially naval surveillance. The heavier-than-air airplane, and the lighter-than-air dirigible thus grew up together.

A dirigible is much more than a gas bag and a basket. Because its body is rigid, it is more readily steered. "Dirigible" means "steerable" in French.

Zeppelin launched his first dirigible in 1900. It used lightweight metal girders to keep the body rigid, and was controlled by two 15-horsepower engines driving propellers. It could fly at 50 miles per hour.

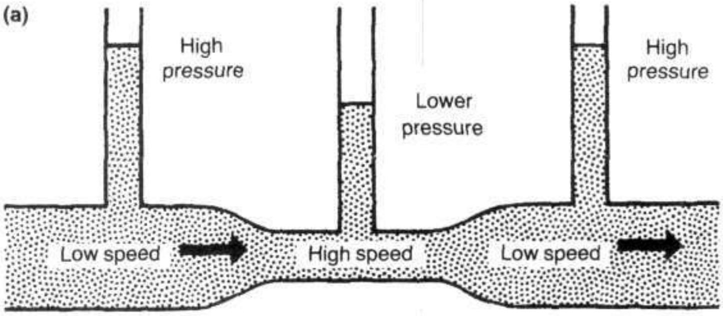
During World War I, the German Navy used Zeppelin dirigibles to



Fred Ferguson's design for a semirigid dirigible, shown here lifting a tank. The sphere is filled with helium at greater than atmospheric pressure, and can rotate on the central axle to produce additional lift from the Magnus effect. The craft is maneuvered and propelled by turboprop engines on either end of the axle. The U.S. Army is interested in having a craft like this for transporting the M1 tank, which weighs about 60 metric tons.

Magnus Aerospace

(a)



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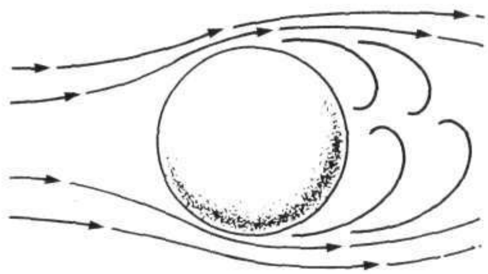


The Magnus Effect

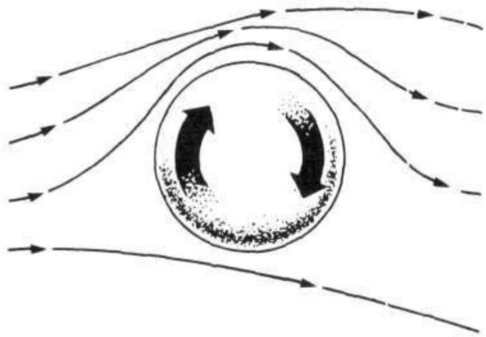
When a liquid or a gas moves across a surface, the pressure it exerts on the surface will decrease if the fluid speeds up. This is called Bernoulli's principle. Diagram (a) shows a flowing liquid being forced to speed up when the tube narrows. The pressure columns show that the pressure is less where the speed is greater. This is a demonstration you could perform yourself with plastic or glass tubing from a scientific supply house.

The Magnus effect is a special case of the Bernoulli principle applied to a rotating cylinder or sphere. If you ever wondered what causes a baseball to "pop up," it is the Magnus effect, first noticed by the German physicist Heinrich Magnus more than a hundred years ago. Here's how it works:

In the nonrotating sphere (b), airflow separates equally from the top and bottom near the midpoint of the sphere.

In the rotating sphere (c), flow remains attached longer to the top side. The sphere's rotation speeds up the airflow. At the bottom side, the rotation goes against the direction of airflow. This causes earlier flow separation. The velocity difference and the downward deflection of the wake produce Magnus lift.

(c)



Magnus Aerospace

scout the North Sea for surface vessels and submarines. After the war, the U.S. Navy took an interest in dirigibles and developed a helium-filled one for long-range scouting over the Pacific Ocean. Two versions of it were built, the *Akron* and the *Macon*.

Both were destroyed in storms at sea, the Akron in 1933, the Macon in 1935. Then in 1937, the famous hydrogen-filled Zeppelin dirigible *Hindenburg*, which had made 36 transatlantic flights, crashed and burned in a storm at Lakehurst, New Jersey. This spelled the end of the huge rigid airships. During World War II, blimps were used for coastal convoys, but the blimp is a smaller, nonrigid craft with very limited maneuverability.

Why did so many dirigibles crash, and why was the dirigible idea abandoned? The flammability of hydrogen gas was not the problem. In fact, the American airships always used helium gas, which does not burn. It was the vulnerability of their large, lightweight frames to sudden stresses in stormy weather that doomed the dirigible. One nasty gust of wind could destroy an airship.

During the 1920s, the future of the dirigible looked rosy, especially since the airplane was a flimsy and very dangerous craft. Dirigibles were ahead of airplanes in transatlantic flight. But during the 1930s, the design of airplanes advanced by leaps and bounds.

Instead of using cloth stretched over wood frames, airplanes were built of metal. A radio system was installed in the cockpit to enable the pilot to stay on course while flying at night or in bad weather. Meanwhile, the best engineering efforts did not produce a dirigible that could stand the strain of storms and compete with the airplane in speed.

A Second Look

Despite the great success of the airplane and the helicopter, the dirigible has been getting a second look, starting in the 1970s. After all, the dirigible does have one feature the airplane and helicopter cannot match—it is lighter than air. No expenditure of fuel is necessary to "get it up." Instead, the greater density of the atmosphere outside the dirigible's helium envelope forces the envelope upward.

For lifting very heavy cargoes, this advantage becomes important. The most powerful helicopter can lift about 15 tons. Dirigibles to lift four times that much weight—and more—are needed for the transpor-

Continued on page 60

Dirigibles

Continued from page 59

tation of heavy construction equipment and military equipment to undeveloped and off-road areas, pipeline construction, the erecting of buildings and transmission towers, loading and unloading cargo ships, disaster relief, and logging where the trees are very large.

If the big dirigibles of the 1930s could not withstand the stress of buffeting winds, what geometric shape would be sturdier? Geometry provides the answer: the sphere. First, the sphere always encloses any given volume with the minimum surface area. Then, because of the sphere's uniformity—the self-similarity of every portion of the sphere to every other—sudden shifts in the wind will produce the minimum stress.

These properties of the sphere are not new discoveries. Dirigibles were designed with cigar shapes because the forward motion of the cigar through the air creates much less drag than the sphere does. When a sphere travels through the air, it creates a vacuum pocket behind it that tends to hold the sphere back—it exerts "drag" on the sphere. At low speeds, the drag is small and unimportant. With increasing speeds, the drag increases rapidly.

Fred Ferguson of Ottawa, Canada, hit upon the discovery that a spherical dirigible was the most efficient way to move very heavy loads. Why spend money on large amounts of helicopter fuel when an envelope of helium will do the lifting without using fuel? The spherical shape makes the craft safe to operate and easily controllable. Many heavy lifting tasks do not require high speed (often only short distances are involved), so the sphere is an acceptable shape.

The Magnus Effect

Ferguson also hit upon the idea of putting to work an additional phenomenon of physics—the Magnus effect. By causing the sphere to rotate about 3.5 times per minute on a horizontal axis as it travels (as shown in the accompanying box) additional lift is generated. To emphasize the usefulness of the Magnus effect, Ferguson calls his company the Magnus Aerospace Corporation.

The craft designed by Ferguson gets 80 percent of maximum lift from helium, and 20 percent from the Magnus effect. The sphere is made of polymer-coated fabric, and filled with helium at more than atmospheric pressure to keep it rigid. The gondola is made of a Kevlar/epoxy composite.

The craft is propelled and maneuvered by four turboprop engines—two on each end of the horizontal axle that passes through the sphere. The gondola for the crew is suspended from the ends of the same axle.

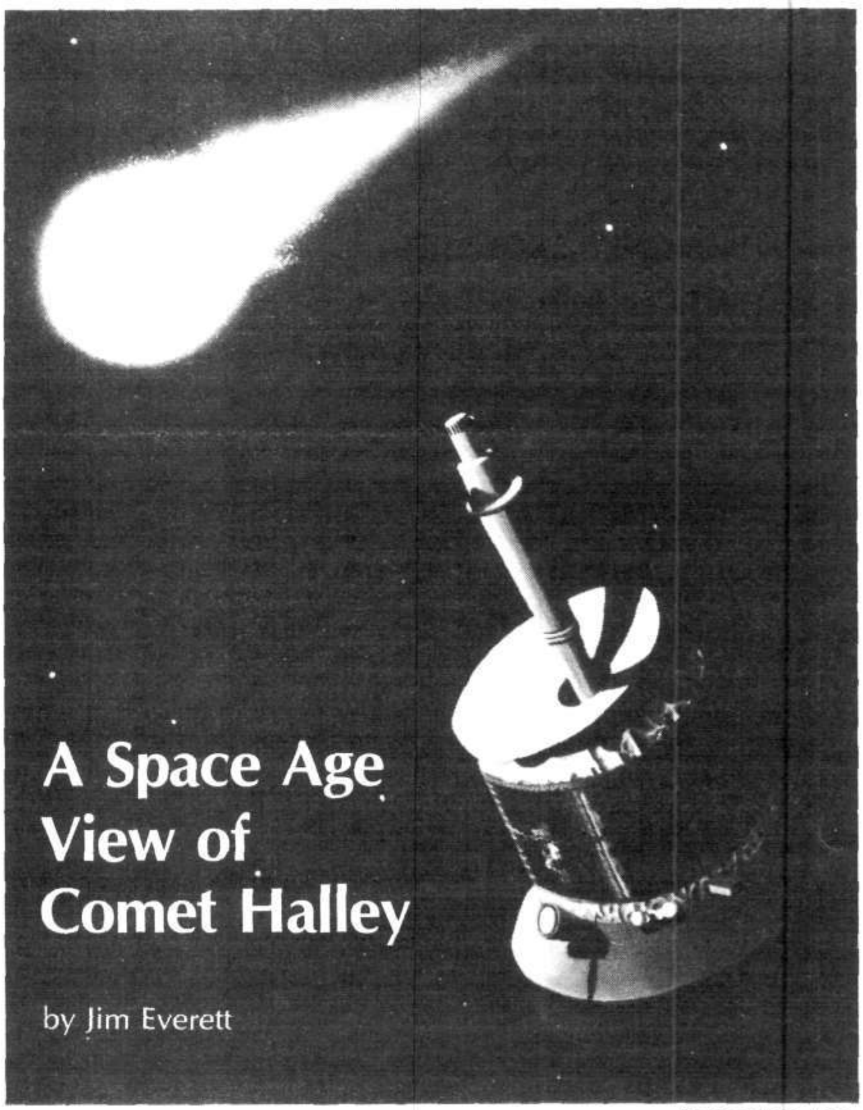
The airship handles like a helicopter. It takes off and lands vertically and needs no ground crew to assist it. It can hover and land using a combination of three capabilities. The Magnus lift can be turned on and off; the engines can rotate on the axle to assist hover or liftoff; and ballast can be used. Compressed air is pumped into a balloon inside the sphere for ballast.

Readers may be disappointed to learn that this wonderful craft has not yet been built. But in 1981, Ferguson built and flew a scale model with a 19-foot diameter. It is too small to carry a pilot, and is remotely controlled. The full scale model will have a diameter of 180 feet and a maximum payload of 60 metric tons. Ferguson says he's prepared to build a version with a 360-foot diameter that would lift 400 to 500 metric tons, if the money becomes available.

To raise enough money to proceed with manufacture of the 180 foot model, Ferguson's company will be issuing stock before the end of 1986. He hopes to get one of the big aerospace companies to help with manufacture.

For Further Reading

The History of the Navy's dirigible program is told in detail in "Up Ship!"—*U.S. Navy Rigid Airships 1919-1935*, by Douglas H. Robinson and Charles L. Keller (*Annapolis: Naval Institute Press*, 1982).



European Space Agency

An artist's illustration of Giotto approaching Comet Halley.

A Space Age View of Comet Halley

by Jim Everett

In 1301, Giotto, the Italian painter who was a friend of the great poet Dante, saw one of the periodic passages of Comet Halley. He painted what he saw into a fresco in the city of Padua several years later and so helped spark the Renaissance passion for the study of nature. Six hundred and eighty-five years later, a space probe named after Giotto was part of an international armada that gave us our first space age view of Comet Halley.

Shooting past the comet 50 times faster than a speeding bullet, the Giotto spacecraft sent back an image of the comet far different from that any of the millions of past viewers could have imagined.

The comet surface is oblong, like a potato, and covered with fissures and vents spewing away gas and dust at a peak rate of more than 12 tons a second. The glow of the comet's tail does not indicate the true color of its surface, which the Giotto revealed to be jet black.

"I'm talking about blacker than coal. It's something like velvet. It's the darkest dark you can imagine," a scientist at the European Space Agency said.

The Giotto spacecraft, launched by the European Space Agency, was just one of a coordinated, international group of spacecraft that observed Comet Halley. Giotto's March 14 flyby was only 324 miles from the core of the comet. The accuracy of the spacecraft's approach was due in part to the observations of two Soviet probes, Vega 1 and Vega 2, that had flown by on March 6 and March 9. On March 8, the Japanese Suisei flew within 125,000 miles and its sister craft, Sakigake, looked on from a distance of 2,000,000 miles.

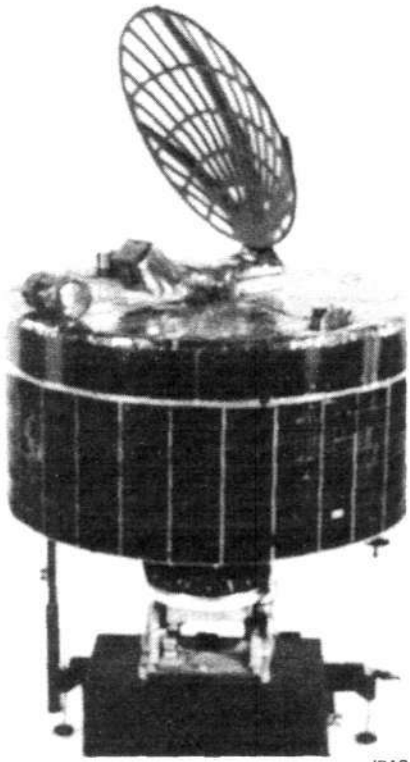
Although the United States did not have a mission dedicated to studying Comet Halley, NASA redirected a number of older spacecraft to look at the comet. One spacecraft originally placed in orbit to study the solar wind was moved into a new orbit to study a comet similar to Halley's, Giacobini-Zinner. After the successful completion of this mission in September 1985, the spacecraft, renamed International Cometary Explorer (ICE), studied the solar wind between the Sun and Comet Halley.

NASA's Comet Watch

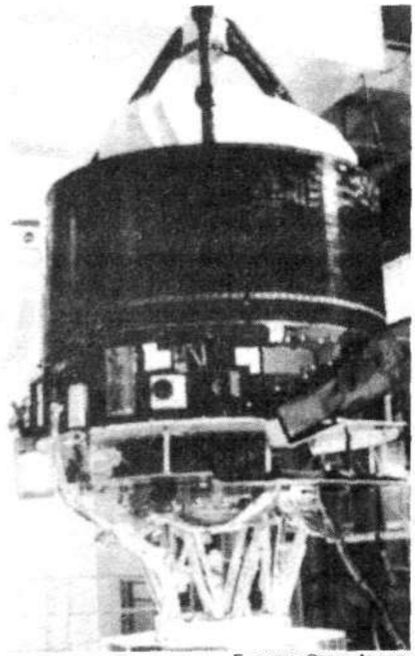
When Halley's was closest to the Sun in February, it was hidden from our view here on Earth. But the Pioneer Venus Orbiter was in position to view it. NASA scientists turned the craft's ultraviolet spectrometer away from Venus for a few weeks to look at the cloud of water vapor around the comet. Another spacecraft, the Solar Maximum Mission, normally looks at the faint corona around the Sun by blocking the Sun's direct light with a disk. The craft used this same technique to see Comet Halley during its closest approach to the Sun.

NASA also sent up the Kuiper Airborne Observatory (KAO) in an airplane to see the comet from high above most of the Earth's clouds and atmosphere. The KAO has a 36-inch telescope inside the belly of a 747 aircraft. Flying over the South Pacific near New Zealand, the KAO saw a huge cloud of dust extending 30,000 miles from the nucleus of the comet.

Finally, on the ground, many observatories directed their telescopes toward the comet in an effort coordinated by the International Halley Watch at the Jet Propulsion Laboratory in California. Two thousand professional and amateur observers have been viewing the comet with a variety of techniques, and all their observations will be assembled by



ISAS
Japan's Suisei spacecraft, launched by the Japan Institute of Space and Astronautical Science Aug. 19, 1985, carried an ultraviolet telescope and an analyzer to measure the energy and direction of electrons and ions in the solar wind.



European Space Agency
The Giotto spacecraft during its testing phase. The 9½-foot tall craft is spin-stabilized, spinning at 15 revolutions per minute. To protect it from the huge impact energy of even tiny dust particles—which can penetrate an aluminum wall 8 centimeters thick—the spacecraft had a two-layer bumper shield. The idea was to spread the impact momentum over a large area.

the International Halley Watch for future reference.

While the international scientific effort directed at Comet Halley has been very successful, it is ironic that the sight of the comet for those of us trying to see it with our naked eye or small telescopes has not been very impressive. This is actually the worst naked-eye viewing of the comet in the last 2,000 years!

The reason is that the comet passed closest to the Sun when farthest from the Earth, and then passed down below the plane of the Earth's orbit as it began to exit the solar system. This made it quite difficult to view from the United States and other northern midlatitude countries.

Why Study Comet Halley?

Why was such a great amount of time, expense, and effort spent to get a good look at Comet Halley? There are sometimes much brighter comets that pass close by, why not look at them? The answer is that we know the orbits of only about a thousand comets well enough to plan a mission to them years in advance. Of these thousand comets, Halley's is the biggest and most active. Many of the other comets have lost most of the water that makes up the bright comet tail. (Comet Halley itself will not be this active indefinitely, since it loses millions of tons of material each trip around the Sun.)

So Halley's is the best comet to study, you might say, but why are comets important to study? One of the big unanswered questions in astronomy is how the solar system formed and what its original chemical composition was like. The composition of the Earth is not the best guide, because for millions of years it has been churned and cooked by geological processes.

Comets, on the other hand, were probably formed at the same time as the planets, and because they are small and cold, their chemical composition reflects the early composition of the solar system. By learning the makeup of a comet, we will learn a good deal about the raw materials of the Earth and the other planets.

Scientists will be analyzing the mountains of data returned from the international fleet of spacecraft and from ground-based observations of Halley's for many years. A few new discoveries have already been made. As mentioned above, the spacecraft Giotto found the surface of Comet Halley to be extremely dark, the darkest object ever seen in the solar system. This indicates a carbon-rich compound, chemically transformed during the repeated close passes to the Sun.

Everyone expected to see jets of water vapor in the close-up pictures, but Vega 1 also saw jets of dust. It flew through one of these dust jets that sandblasted away 80 percent of the solar cells supplying power to the spacecraft. The Vega craft saw the comet's nucleus through a "dust cocoon," which probably prevented them from seeing the nucleus itself. The Giotto photographs were made from as close as 900 miles to the comet's core and revealed the actual fissures and vents through which the gas and dust were escaping.

A Close Call

All of the spacecraft survived the close flyby with Comet Halley, but just barely. Because the comet has a retrograde orbit (that is, it moves around the Sun in a direction opposite from that of the Earth), the Earth-launched spacecraft had to pass by the comet at a very high speed relative to the comet. Passing through the dust cloud at 150,000 miles an hour is no way to treat a spacecraft. The Vega solar panels were badly damaged and Giotto's camera stopped working 2 seconds before closest approach. They were just sandblasted to death. These craft can still be used again for future missions, although no missions are planned at the moment. The most ambitious plans are to send a new spacecraft to a comet rendezvous, where the probe would orbit alongside the comet for an extended period of time, avoiding the dangers of a high speed encounter.

Books Received

The Economics of the Nuclear Fuel Cycle, Nuclear Energy Agency, OECD. Paris, 1985. Paperback, 169 pp., $25.

Electricity in IEA Countries: Issues and Outlook, Nuclear Energy Agency, OECD. Paris, 1985. Paperback, 379 pp., $46.

Radiant Science, Dark Politics—A Memoir of the Nuclear Age, by Martin D. Kamen. University of California Press, 1985. Hardcover, 348 pp.

Controlling the Atom—The Beginnings of Nuclear Regulation 1946-1982, by George T. Mazuzan and J. Samuel Walker. University of California Press, 1985. Hardcover, 530 pp.

The Isotropic Universe—An Introduction to Cosmology, by D.J. Raine. Adam Hilger, 1981. Hardcover, 253 pp.

Project Space Station—Plans For a Permanent Manned Space Center, by Brian O'Leary. Stackpole, 1983. Hardcover, 159 pp., $12.95.

Spacelab—Research in Earth Orbit, by David Shapland and Michael Rycroft. Cambridge, 1985. Hardcover.

Muon and Muonium Chemistry, by David C. Walker. Cambridge, 1983. Hardcover, 179 pp., $49.50.

Classical Mechanics, by Edward A. Desloge. Wiley-Interscience, 1982. 2 vols. Hardcover, 990 pp., $111.

Encyclopedia of Physics, Rita G. Lerner and George L. Trigg, eds. Addison-Wesley, 1981. Hardcover, 1157 pp.

Leibniz—A Biography, by E.J. Aiton. Adam Hilger, 1985. Hardcover.

Telescopes, Tides and Tactics—A Galilean Dialogue about the *Starry Messenger* and Systems of the World, by Stillman Drake. University of Chicago Press, 1985.

Command Under Sail—Makers of the American Naval Tradition 1775-1850, James C. Bradford, ed. Naval Institute Press, 1985. Hardcover, 333 pp.

The Internal-Combustion Engine in Theory and Practice, by Charles Fayette Taylor. 2nd edition revised. MIT Press, 1985. 2 vols. Hardcover, pp. 574 and 783.

Directory of Federal Laboratory and Technology Resources—A Guide to Services, Facilities, and Expertise. U.S. Department of Commerce NTIS, 1986. Paperback.

Assessing Medical Technologies, by the Institute of Medicine. National Academy Press, 1985. Hardcover, 573 pp., $42.50.

Biotechnology—An Industry Comes of Age, by Steve Olson. National Academy Press, 1986. Paper, 120 pp., $9.95.

Astrophysics for Beginners

100 Billion Suns—The birth, life, and *death of the stars*,
by Rudolf Kippenhahn.
New York: Basic Books, 1983. pp. 264.

The Physics of Stars,
by S.A. Kaplan.
New York: John Wiley, 1982. pp. 158.

Principles of Stellar Evolution and Nucleosynthesis,
by Donald D. Clayton.
Chicago: University of Chicago Press, 1983. Paperback.

There are dozens of introductions to astronomy of varying degrees of difficulty and rigor. In the newer field of astrophysics there are some popular books, but probably there was no straightforward introduction for the layman until the appearance of *100 Billion Suns* by Rudolf Kippenhahn, director of the Max Planck Institute of Astrophysics. The book is in part an adventure in discovery. The author often recreates a question asked by astrophysicists and the uncertain state of their knowledge, and then shows how the answer was approached. The author and his associates participated in some of the investigations he recounts. Kippenhahn's treatment is nonmathematical, and has excellent diagrams of, for example, stellar fusion reactions and stellar models.

The Physics of Stars is by the Soviet astronomer S.A. Kaplan, of Gorky University until his death in 1978. This is a terse book with emphasis on physical understanding. It is a shirtsleeves work full of interesting calculations. The math is simple, with only occasional use of logarithms. Those who have digested Kippenhahn's book may wish to try Kaplan's.

Principles of Stellar Evolution and Nucleosynthesis is a full-length graduate textbook used in the education of astrophysicists. It is a paperback reprint of the 1967 edition with a new preface to guide students to the subsequent literature.

Naval History

Bull Halsey,
by E.B. Potter.
Annapolis: Naval Institute Press, 1985. pp. 421.

This biography of Admiral William Halsey is written by the U.S. Naval Academy professor who won acclaim with his biography of Admiral Nimitz. In 1944, Halsey became commander of the Third Fleet, which comprised most of the strategic forces of Nimitz's Pacific Fleet. Because it reads almost like a novel, the reader may lose sight of the fact that this is a scholarly work.

Potter reports that Halsey shared the hostile view of MacArthur common among Navy brass, and tells how his scorn and resentment were fueled by his own communications with MacArthur. Halsey decided to beard the "self-advertising son of a bitch" in his den, and proposed a meeting. Halsey's prejudices evaporated in the course of this encounter. MacArthur later wrote of Halsey, "the bugaboo of many sailors, the fear of losing ships, was completely alien to his conception of sea action." The cooperation established between Halsey and MacArthur was important to the war in the South Pacific.

Inertial Confinement Report

Continued from page 20

be at issue. Meanwhile, the Nova program, with 50 kJ of blue light, will at most provide a hydrodynamic replica of a high-gain target, and will probably not give a clear indication of a runaway excursion.

To help resolve this issue we have requested that the laboratories provide the Committee with their judgment of an approach to obtaining data which would constitute important milestones. These milestones should start from results expected with present capabilities, and lead up to what would be eventually achievable with the energy and pulse characteristics of a driver which could give a real thermonuclear burn with significant gain in the laboratory.

Classification

Classification of much of the ICF Program is a difficult problem which is hindering progress by restricting the flow of information. These restrictions are hurting the morale of imaginative scientists who are unable to take credit for their creative work, and who must often endure the vexation of seeing nearly identical work published in the open literature some years later by workers from Japan, Europe, or the Soviet Union. Classification also keeps the scientific public from fully appreciating the important progress which has been made by the ICF Program, or from criticizing its weaker parts. A more widespread understanding of the achievements of ICF would make it easier to support the higher-priority parts and to deemphasize the less urgent parts of the program. We recommend the formation of a high-level committee to review the issue of ICF classification and to formulate new, more realistic and flexible classification guidelines.

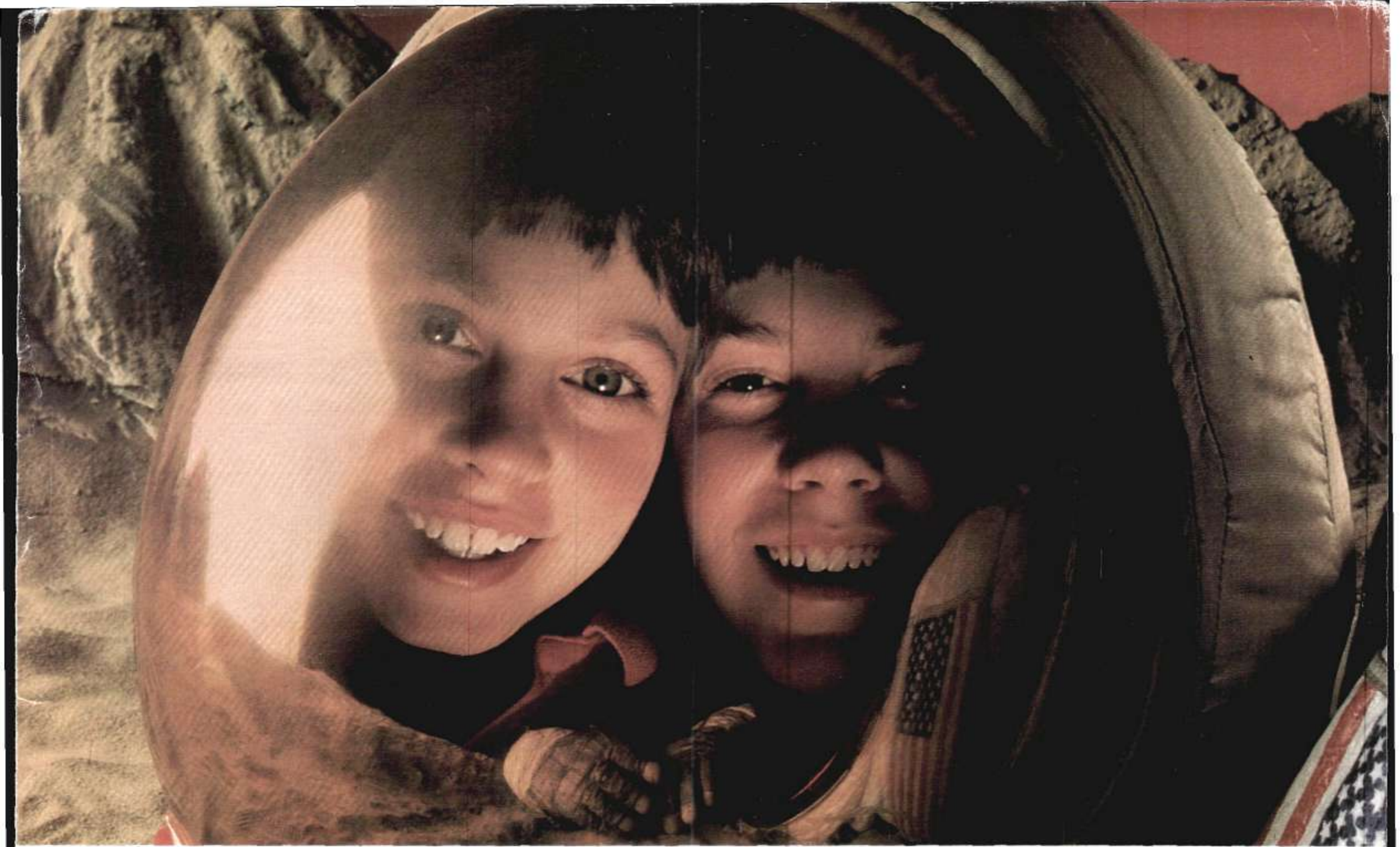
One of the most serious problems of the ICF Program is the erratic funding plans which have characterized the establishment of DOE budgets in recent years. A major fraction of the program management's energy is devoted to coping with the annual budget crisis. The program is making very good progress toward the goal of igniting a thermonuclear burn in a laboratory pellet. As we stressed earlier, the attainment of this goal would be of great immediate importance to the U.S. weapons program, and it could have a long-term impact on the commercial generation of electrical power. Steady, rational funding of the program is essential for the next few years while the capabilities of the new facilities of PEBFA II and Nova are being exploited and evaluated.

The ICF Program has traditionally been identified as a line item in the DOE budget. The Committee feels that this program identity should be maintained. There are serious problems with including the ICF Program in the RDT&E portion of the DOE weapons program. Separate line-item funding of the ICF Program would facilitate the support of the smaller groups at the Naval Research Laboratory, the University of Rochester, and KMS Fusion. Finally, it would make the spotting of failures, as well as successes, of the program easier with priorities adjusted accordingly.

The ICF Program would clearly benefit from a permanent advisory committee which could provide the kind of long-term perspective which ad hoc committees like this one cannot. The composition of such a standing committee would have to be carefully chosen to give sound, impartial, and informed advice to both the laboratories and DOE management. The DOE's Magnetic Fusion Advisory Committee (MFAC) and High-Energy Physics Advisory Panel (HEPAP) provide excellent working models of the advisory committee we have in mind.

As stated at the outset, the Committee still has much hard work to do before it can produce a final report of its findings. A number of program elements must be evaluated in greater detail than available time has thus far allowed, and other elements—such as the work on heavy ions—have yet to be addressed. The remaining work will begin with a one-week concentrated effort in San Diego on August 5-9, 1985. We fully expect that our final report will be made available to you by the date you requested.

Please know that the Committee is available to respond to any questions which may arise from this interim report.



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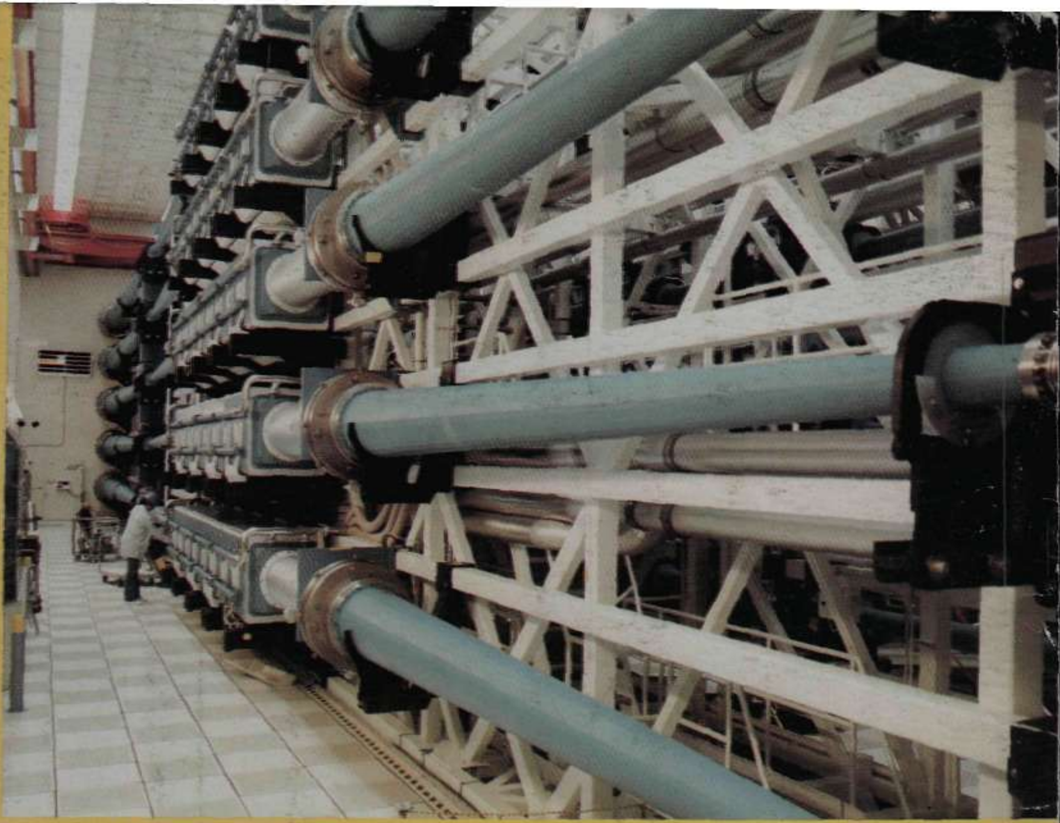
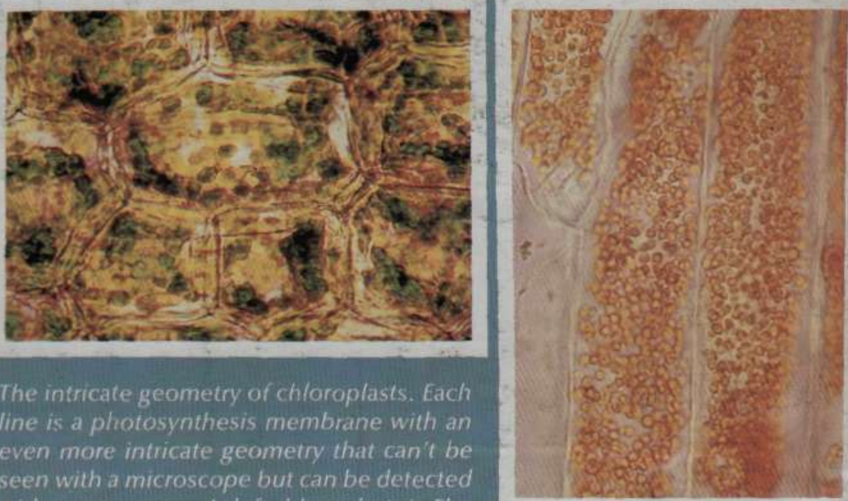


Laser technician making the final adjustments on the amplifier of Nova, the world's most powerful laser.

Lawrence Livermore National Laboratory

The Shuttle Orbiter Columbia being gently lowered down toward the solid rocket boosters and external tank for mating.

NASA



The intricate geometry of chloroplasts. Each line is a photosynthesis membrane with an even more intricate geometry that can't be seen with a microscope but can be detected with spectroscopy. At left chloroplasts in Elodea leaf cells and at right tulip chloroplasts in petal cells, both magnified 225 times.

Biophoto Associates/Science Source

In This Issue

'NO PHYSICAL OBSTACLES' TO ACHIEVING INERTIAL CONFINEMENT FUSION

Instead of a proud announcement by the President that the U.S. inertial confinement fusion program had made "striking progress" in the past few years and there were now no physical obstacles to achieving success, the White House sat on a favorable review of the program by the National Academy of Sciences for eight months. We reprint that report in full, and tell the story of how fusion scientist Stephen O. Dean fought to get the report out of the deep freeze. That the United States will achieve fusion breakeven is clear from the report. The only question remaining is whether the administration will use budget cuts to keep laser fusion in limbo.

THE SECRETS OF PHOTOSYNTHESIS

The same advanced spectroscopy techniques of nuclear magnetic resonance that are helping doctors see what's going on in the human body are helping scientists unravel some of the mysteries of how plants photosynthesize. Ned Rosinsky describes the complex geometry involved and discusses how chlorophyll acts like a molecule-sized antenna sending and receiving electromagnetic signals.

HOW THE SPACE SHUTTLE SYSTEM WAS SABOTAGED FROM THE BEGINNING

Even before manned exploration of space was technologically possible, there was a faction that tried to stop its development. Marsha Freeman shows how the opponents of the space program undercut the Shuttle program from its inception, using the budget axe as their weapon. If any safety compromises have been made, she says, the blame lies with these budget cutters.