FUSION

SCIENCE • TECHNOLOGY • ECONOMICS • POLITICS

December 1981

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SPECIAL REPORT
There's Plenty of Oil and Gas!

Building Cities in The Solar System

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Overturning Equilibrium Economics
FUSION
JAPAN
Number 1 in Fusion?

Young Scientist
The Young Scientist
The Shuttle's next stop—
The Young Scientist
Exploring the frontiers of the 1980s

An Appeal to Readers of Fusion From the Wertz for Senate Campaign

California Governor Jerry Brown and his political controller Tom Hayden are committed to dismantling the U.S. nuclear industry. Tom Hayden's organization, the Campaign for Economic Democracy (which Brown depends on for support), is the most visible counterpart in the United States to the environmentalist "green" fascists now rampaging throughout Europe.

- **In 1978,** Jerry Brown killed the Sun Desert nuclear plant and created the SolarCal Council, as proposed by Tom Hayden. That same year, he appointed Hayden to represent the state of California on the federally funded solar promotion agency—Western SUN.
- **In 1979,** Brown appointed Hayden to chair the SolarCal Council.
- **In 1980,** Hayden called upon Brown to prevent the Diablo Canyon nuclear plant from starting up and to phase out the state's two operating plants, San Onofre and Rancho Seco. When the Hayden-allied Abalone Alliance failed to prevent Diablo Canyon from gaining an operating license, Jerry Brown personally went to court and, along with his allies, put massive pressure on the Nuclear Regulatory Commission to suspend the plant's license.

Will Wertz, the primary opponent of Jerry Brown for the Democratic nomination for U.S. Senate and the former Western States Coordinator for Lyndon H. LaRouche's National Democratic Policy Committee, needs your help to ensure that neither Jerry Brown nor Tom Hayden (running for State Assembly in California) ever again hold public office in this country. In opposition to Tom Hayden's brownshirts, Wertz is committed to the construction of more than 100 billion watts of nuclear electricity-producing capacity to be completed between now and 1986-87, plus an additional 50 billion watts by about 1990.

Vote human for a change! Send contributions to:

Wertz for Senate

711 S. Vermont #207, Los Angeles, Calif. 90005 (213) 383-2912

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Paid for by Wertz for Senate, Martin Simon, treasurer.

NASA

Twelve years ago, man explored the Moon; now we have the capability to colonize it. In the first of an exciting two-part series, Dr. Krafft Ehricke explains how this can—and must—be done. Above Apollo 17 astronaut Harrison Schmitt stands next to a huge lunar boulder.

Features

The first part of Fusion's two-part series on the untapped potential of the American West examines exploration geochemistry, a proven technology for mapping oil and gas deposits in subtle traps, like those in the Rocky Mountains.

News

Departments

From the Editor's Desk

A year ago, we were celebrating the signing into law of the Magnetic Fusion Energy Engineering Act of 1980, which committed the nation to building an engineering model reactor by 1990 and a commercial prototype reactor by the year 2000. This was a law that *Fusion* readers had helped pass by sending thousands of postcards of support to the President and to the bill's chief congressional sponsor, Rep. Mike McCormack.

Today, as we go to press, the administration has cut the fiscal year 1982 fusion budget from the $525 million mandated in the law to a barebones level of $405 million, and three major fusion projects will be eliminated—the ISX-C, the FMIT, and the EBT-P. At the same time, the NASA program is again being chopped.

The cuts occur just as President Reagan has become the first president in a long while to issue a pronuclear policy. Yet, these pronuclear sentiments are not enough to reverse the nation's slippage from world scientific leadership. In the first place, without a fully funded program for scientific research of the sort exemplified by the fusion program and by NASA's science programs, the American tradition of scientific progress will grind to a halt. We are cutting off our ability to solve tomorrow's problems. Second, as documented in this issue's Nuclear Report, financial warfare in the form of high interest rates has forced the cancellation of several nuclear plants in the past few months, and the situation is getting worse. Unless the Federal Reserve's interest rate policy is turned around, the nuclear industry may be forced into early retirement despite the President's good intentions.

Fusion readers are President Reagan's constituency. We urge you to send this issue's postcard to the President in support of America's scientific research and science education programs.

Marjorie Mazel Hecht

Marjorie Mazel Hecht
Managing Editor

Warning to Subscribers

We have severed all relations with "Inform America," a group based in Detroit that was soliciting *Fusion* subscriptions by telephone. "Inform America" is not authorized to use our subscriber list, and we in no way endorse or condone any financial offerings or solicitations currently made by this group or persons affiliated with it, using the name "Labor Beacon," "Parity Foundation," "ProVest," or "Renaissance Prints." Any complaints or requests for verification should be sent to the FEF office in New York City.

FUSION
AT THE FRONTIERS OF SCIENCE AND ENERGY

Vol. 5, No. 2 December 1981

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The views of the FEF are stated in the editorials. Opinions expressed in articles are not necessarily those of the FEF directors or advisory board.

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Subscribers: Because of financial difficulties, this is the first issue we have mailed since Nov. 1981. Please be assured that you will receive all the issues you have paid for.

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The cover: The Space Operations Center is shown above the Earth communities of Houston and Galveston, Texas. Illustration by John J. Olson, courtesy of Boeing Aerospace Co. Cover design by Virginia Baier.

Resources Are Not Finite

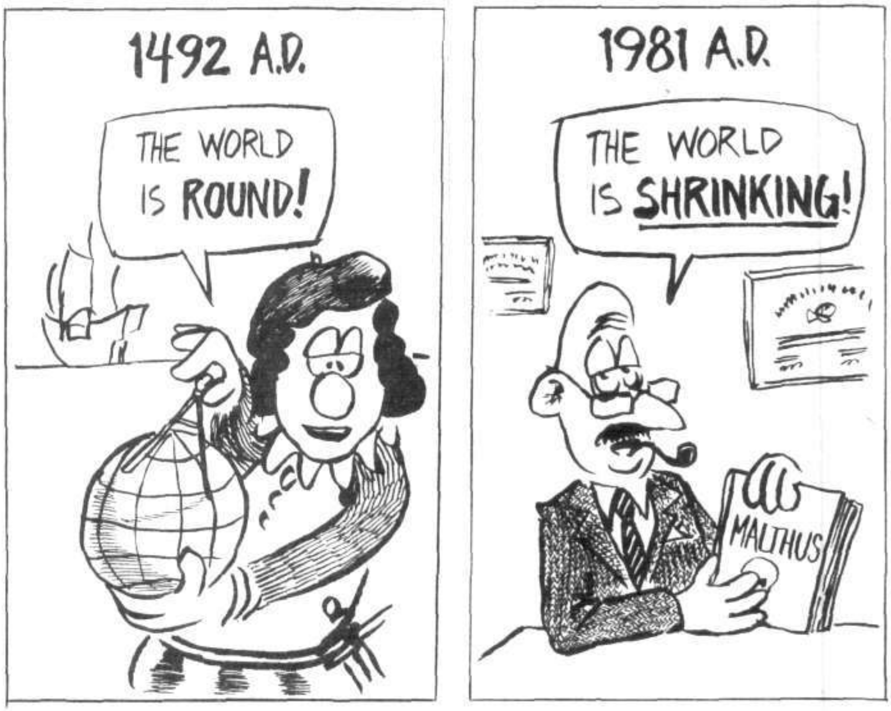
The most persistent and pernicious myth of the neo-Malthusians is that of "finite resources." The historical existence of man to the contrary, Malthusians of all persuasions ultimately ground their fear of progress and growth on the bugaboo of unlimited growth in a world of finite supplies.

At every point in man's history when a so-called crisis of resources has been confronted, new resources were *created*—new energy supplies, new industrial raw materials, and even more land. The historical record on this is unequivocal and completely open. Man has never depended on "natural resources"; he has always created resources.

Nevertheless, the myth of finite resources lives on. Modern military thinkers like James Schlesinger and General Maxwell Taylor base grotesque parodies of military strategy on this myth; pseudothinkers like Jeremy Rifkin and Paul Ehrlich base popular horror stories on this myth; and some, like futurists Hazel Henderson and Willis Harmon, would fabricate a new religion based on the animalistic morality of a finite earth.

The widespread corollary in the minds of many people who are not Malthusians is the necessity of conservation. Since the resources we have at our disposal are finite, they argue, we must be prudent in our consumption. The more radical even suggest that it is an outrage that 35 percent of the world's resources are consumed by the 6 percent of the world population in the United States.

What could be more absurd? If needed resources are finite, conservation only shifts the burden of ultimate depletion onto our descendants. The fact is that consumption is not an end in itself; it is the beginning of a process of transformation and creation of new resources. The share-the-wealth moralists who enjoy the fruits of American consumption neglect to mention that precisely because the United States consumes 35 percent of the world's



resources, it accounts for approximately the same proportion of the world's production.

Solving the Problem

The antidote to this neo-Malthusian drivel does not, of course, lie in the rightful disgust that this nonsense inspires, but rather in attending to the practical problem of solving man's problems today to ensure the invention of the new resources that we and our children require.

Space exploration is only the first step toward the physical expansion of man's dominion. Specifically, our solar system must be industrialized and urbanized. We can and must create new cultures of men. *Selenians,* as described by Dr. Krafft Ehricke in this issue, have an enviable future ahead of them, as long as they do not first become demoralized by the Flat-Earthers here who would assure us that there is no new frontier.

We Earthlings, too, have a future of unbounded plenty in both material and cultural terms, using new technologies like the fusion torch that create new raw materials and, at the same time, transform the matter we inherit from the universe, using nuclear processes that were, until now, the unique province of the stars themselves. The family of technologies called advanced isotope separation and generation puts in our hands the ability to create new elements, to tailor their properties in the same way that we mix alloys today.

The application of technology to resource creation is also the subject of our two-part Special Report on the "Untapped Potential of the American West," which this month covers uranium and oil and gas. Next month, part two will discuss how California, once a desert, has bloomed; how water was created for irrigation, land was reclaimed for agriculture and recreation, and most important, how California's scientific laboratories produce astounding new ideas for the accelerated continuation of this process.

California is a case study for the true environmentalists. Man's role here on Earth is not that of an innocent bystander, but of an architect and master builder. The Earth and soon the solar system are our responsibility.

This future is not any more inevitable than the death by entropy that the Malthusians predict; new technologies and new resources can be created by man today. It is primarily a question of our ability to perceive the necessity of growth and development.

The Lightning Rod

My dear friends,

I'm told that NASA receives many odd requests from persons seeking to purchase cargo room on the Space Shuttle; yet I believe the oddest of all crossed my desk last week, from a fellow requesting my assistance in helping him secure an entire payload, to be jettisoned in space, "so that if there's anyone out there, they'll know what happened." The cargo, now on its way from the Midwest by boxcar, is the entire court record pertaining to "the projected construction of a public power facility on the Perskippany River, said facility to be fueled by the means commonly known as a light water reactor." I quote further from my correspondent's summary of the case:

* * *

"In 1969 (so long ago that Richard Nixon was our President), the Perskippany Public Power Company filed for a construction permit to build a nuclear plant near our city. Moments before the state's regulatory authorities planned to announce the granting of the permit, a suit was filed to enjoin construction. This suit, *Friends of the Water Vole Versus Perskippany Public Power Company and State Regulatory Commission,* was the beginning of all our troubles.

"Friends of the Water Vole argued that construction of the plant would 'irreparably damage the habitat and disturb the mating patterns of this rare species of vole indigenous to the lower Perskippany.' The power company argued that our nearby city required additional electrical power, and that nuclear energy was the cheapest and most reliable way to produce it. Our electric bills were up to $20 a month, they pointed out, and nobody

Continued on page 6

The Lightning Rod

Continued from page 5

was happy about it.

"A couple of years later, after a number of motions, cross-motions, and double-cross motions, it finally looked like the problem might be solved when the power company, in the interests of public relations, offered to move all the water voles on the lower Perskippany to the upper Perskippany, where they would not be affected by the plant construction. A permit was granted and plant construction began.

"The voles, however, refused to cooperate by making themselves available for transportation; not a vole could be found in the neighborhood. Then, Friends of the Water Vole announced that the creature was even rarer than it had thought, simultaneously charging the company with bad faith in failing to use proper, professional vole-locating procedures. So negotiations broke down, and soon the suit was expanded to include the Perskippany County Board of Selectmen, the State Public Service Commission, the Rivers and Harbors Administration, the Environmental Protection Agency, the Army Corps of Engineers, the Atomic Energy Commission, the World Wildbeast Society, the Asp Institute, and the SPCA. It took two more years just to figure out who was suing whom, and why.

"By the time the case came to trial, Gerry Ford was President, everyone was wearing WIN buttons, and our electric bills were up to $35 a month. There were quite a few newspaper headlines, and Lou Harris even sent a man to the lower Perskippany to poll the voles to see how they felt about it, but he couldn't find any either.

"What with the post-Watergate climate and all the investigative reporters with time on their hands in our city, however, it came out that the president of the Perskippany Public Power Company had been lying to everyone for years about his score on the CPA examination. I don't have to tell you how that set back prospects for completion of the Perskippany nuclear power plant.

"Then, right in the middle of the trial, a truly sensational development occurred. Just when it seemed the judge was about to rule in favor of the environmentalists and permanently halt construction on the plant, his cat sauntered into the courtroom carrying a small, furry, rodentlike creature in his jaws. The entire plaintiff's table exploded in shrieks and screams, as the Friends of the Water Vole piled onto the cat as if he were Dillinger. When the pandemonium subsided, the cat having been disengaged from his prey, the plaintiffs approached the bench to show His Honor a somewhat disheveled but apparently uninjured water vole.

" 'You made all this fuss on account of a rat?' the judge exclaimed.

"So the plant was completed, which was a good thing, because by that time Jimmy Carter was President, and in a couple of years our electric bills had gone up to $65 a month—and then came Three Mile Island. Now nothing like that had ever happened at our Perskippany plant, but every-body was suddenly very safety conscious, and Ralph Nader charged that the plant had a serious design defect because no adequate provision had been made to ensure that a water vole couldn't get stuck in the intake valve.

"So the Nuclear Regulatory Commission shut down the plant until modifications could be made on the intake valve to ensure that, even if it was trying very hard, no water vole could get stuck in the valve. Before too long, though, Ronald Reagan was elected President, and we were all pretty happy. There wasn't much more work to be done before the plant could open up again, and the President had promised during his campaign that he would do away with 'unnecessary delays' caused by 'excessive regulation.'

"Then a new suit was filed by the United Consumers and Taxpayers of Perskippany County to prevent 'the expenditure of any city, county, state, or federal funds, or funds of enterprises subject to state, city, county, or federal regulatory authority for continued modification or operation of the Perskippany Nuclear Power Plant.'

"United Consumers complained that the plant had cost 'three times its original estimate to build' and had 'proven itself liable to lengthy shutdowns,' that interest rates were over 20 percent, and that 'the all-important goal of a balanced budget must not be jeopardized by continuation of uneconomic pork barrels.'

"The word around town is that the power company plans to settle out of court and purchase more electricity from Canada. Our electric bills are up to $90 a month."

* * *

Although sympathetic to my correspondent's desire to preserve a record for some perhaps more advanced civilization, I hope his story may yet do some good here on earth.

Yr. obt. svt.

Benj. Franklin

Global 2000: A Refutation

David R. Barnes

by Julian L. Simon

Now the *Global 2000 Report* makes it official that the world is going to hell in a handbasket. This is the report's own thumbnail summary of the *Global 2000* findings:

"If present trends continue, the world in 2000 will be more crowded, more polluted, less stable ecologically, and more vulnerable to disruption than the world we live in now. Serious stresses involving population, resources, and environment are clearly visible ahead. Despite greater material output, the world's people will be poorer in many ways than they are today.

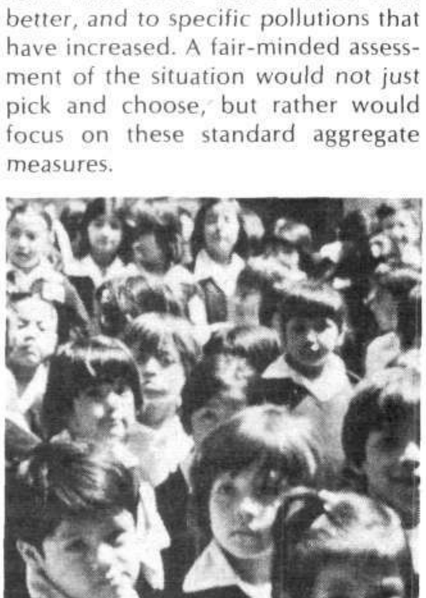
"For hundreds of millions of the desperately poor, the outlook for food and other necessities of life will be no better. For many it will be worse. Barring revolutionary advances in technology, life for most people on earth will be more precarious in 2000 than it is now."

Fortunately, these assertions about resources and the environment are baseless. The authors of the *Global 2000 Report* offer no persuasive evidence for their "scenario." The facts, as I read them, point in quite the opposite direction on every single important aspect of their prediction for which I could find any data at all.

Item: "more polluted." *Global 2000* says, "The life expectancy of a population is the most all-inclusive and widely measured indication of a nation's environmental health," and I agree. The data show continued increase in U.S. life expectancy, and at an increasing rate—a gain of 2.6 years from 1970 to 1976, compared with a gain of only 0.8 during the entire decade of the 1960s. By this test, the environment certainly is healthier than ever before.

"The rate of increase of life expectancy has slowed," *Global 2000* says. The report's own data show the opposite, however. It reports life expectancies for the world population as follows: 46.7 in 1950-55; 49.9 in 1955-60; 52.2 in 1960-65; 53.9 in 1965-70; 58.8 in 1975. And these crude figures certainly understate the gains within particular countries, because the countries with lower life expectancies have a successively bigger weight in the calculation for the more recent years due to their increasing share of total world population.

Of course, one can point to specific places where environmental conditions have fared worse rather than better, and to specific pollutions that have increased. A fair-minded assessment of the situation would not just pick and choose, but rather would focus on these standard aggregate measures.



Carlos Mendez

There never have been any empirical data showing that popuation growth has a negative effect.

What trend data does the *Global 2000 Report* rely on for its frightening "projections" of the environment's pollution level? I could find none. There are frequent references from one chapter to another, but when arriving at the destination I often found no data, only reference to another elsewhere. Then in the chapter on "analysis," which describes the method used, we read that "There is at present no adequate, formal, and precise means of projecting world trends for renewable resources such as water, forestry, fisheries, soil, and the environment."

Item: "serious stresses involving . . . resources." There have always been "serious stresses" in the sense that people have to pay a price to get the resources they want. But the data on "stress," as measured by the relevant economic measures of scarcity—costs and prices—show that the long-run trend is toward less scarcity and lower prices rather than more scarcity and higher prices, hard as that may be to believe. The cost trends of almost every natural resource—whether measured in labor time required to produce the resource, in production costs, in the proportion of our incomes spent for resources, or even in the price relative to other consumer goods—have been downward over the course of recorded history.

An hour's work in the United States has bought increasingly more of copper, wheat, and oil from 1800 to the present. And the same trend has almost surely held throughout human history. Calculations of expenditures for raw materials as a proportion of total family budgets make the same point even more strongly. These trends imply that the raw materials have been getting increasingly available and less scarce relative to the most important and most fundamental element of life, human work-time.

The relative fall in the prices of raw materials understates the positive trend, because as consumers we are interested in the services we get from the raw materials rather than the raw materials themselves. And we have learned to use less of given raw materials for given purposes, as well as to substitute cheaper materials to get the same services. For example, a single communications satellite in space provides intercontinental telephone connections that would otherwise require thousands of tons of copper. That is a dramatic example of how the service that copper renders can be supplied much more cheaply by a substitute process.

Item: Population. The *Global 2000 Report* recommends that the United States should "cooperate with other nations in efforts to relieve poverty and hunger, stabilize population, and enhance economic and environmental production." But there are not *now, and there never have been,* any empirical data showing that population growth or size or density have a negative effect upon the standard of living, the level of pollution, or any other important measure of human welfare. This has emerged from historical time-series studies, and from cross-sectional studies of both more developed and less developed countries. And this nonfinding is the more persuasive because it is the case despite the zealous efforts of large numbers of researchers who have sought to back their Malthusian logic with empirical proof. There is, therefore, no general reason other than personal intuition to conclude that population growth is necessarily for the worse—unless one simply believes that human beings are an evil in themselves, *or that human life is too horrible to* be lived.

Julian L. Simon is a professor in the Department of Economics and Business Administration, University of Illinois at Urbana. This viewpoint is adapted with the author's permission from "Global 2000, 1980: A hard look at the Global 2000 Report," which appeared in the winter 1981 issue of The Public Interest, *copyright National Affairs, Inc.*

Letters

Space Colonization and Advanced Technology

To the Editor:

The pamphlet "On to the Next Frontier" is an outstanding document, and I congratulate the Fusion Energy Foundation for a job well done. . . .

I'm not sure why the Fusion Energy Foundation is taking such an interest in space—perhaps it's because it is interested in all "advanced technology"—fusion and space included. I believe you are quite right that the space program needs fusion propulsion as the next real breakthrough, especially if we venture out of the solar system, but I'm not sure how space exploration and colonization helps the fusion energy program. Perhaps they support each other in the general milieu we term "advanced technology." Anyway, thanks for the boost.

By the way, it's not clear why you are so negative about Gerry O'Neill's activities. Both of you wish to colonize the moon, *his* for commercial purposes, yours for "exploration and colonization" purposes. It's true he hopes to use solar energy for his prime source of energy, but I'm sure he would not reject fusion if it were to be available by 1990-2000 in light weight form (inertial fusion conceivably could be, but I doubt that magnetic fusion will ever be in our lifetimes). At any rate, that is the only negative thought I see in your pamphlet.

One idea expressed on page 4, I had not heard before: "Once the human race ceases to progress . . . [it] becomes a gang of lotus eaters, of parasites." I sincerely believe that, and I suspect instinctively so do most humans. We can't expect to live off the efforts of our forebearers and leave nothing to our descendants. That does indeed make us parasites!

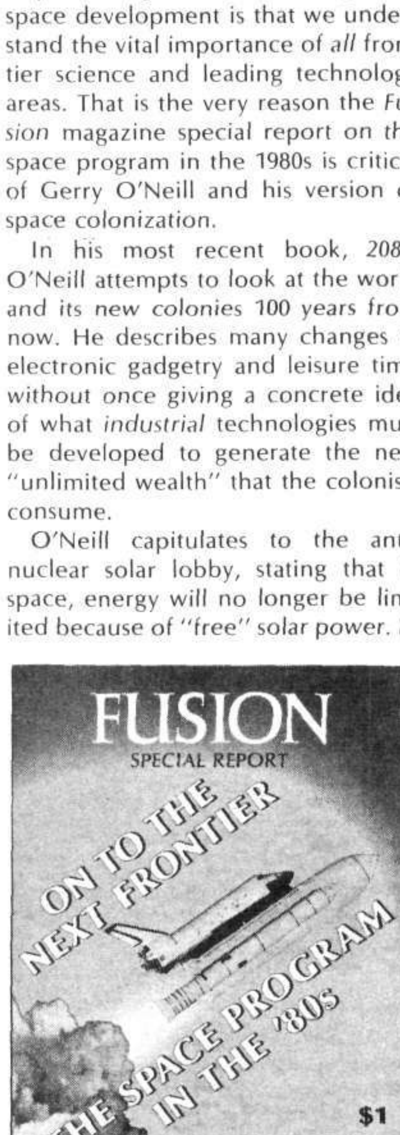
James C. Fletcher
Whiteford Professor of Energy Resources and Technology,
University of Pittsburgh,
(former NASA Administrator, 1968 to 1972)

The Editor Replies

Dr. Fletcher is precisely right. The reason the Fusion Energy Foundation is promoting advanced energy and space development is that we understand the vital importance of *all* frontier science and leading technology areas. That is the very reason the *Fusion* magazine special report on the space program in the 1980s is critical of Gerry O'Neill and his version of space colonization.

In his most recent book, *2081*, O'Neill attempts to look at the world and its new colonies 100 years from now. He describes many changes in electronic gadgetry and leisure time without once giving a concrete idea of what *industrial* technologies must be developed to generate the new "unlimited wealth" that the colonists consume.

O'Neill capitulates to the antinuclear solar lobby, stating that in space, energy will no longer be limited because of "free" solar power. In



"On to the Next Frontier: The Space Program in the '80s," a 24-page Fusion *report, is available from the Fusion Energy Foundation at $10 for 10 copies, postpaid.*

his economic evaluation of using solar energy to power space colonies, O'Neill compares its cost to the current cost of Earth-based solar, never to conventional nuclear or the fusion energy that will surely be available in 100 years. Indeed, in his discussion of energy, O'Neill assumes that fusion will not be ready, outdoing even the most extreme antitechnology factions of the former Carter Department of Energy, who admitted fusion energy would be in widespread use in at least 50 years.

O'Neill dismisses fusion space propulsion as "unnecessary," even though the most fertile minds in space colonization (among them Fletcher) understand that only fusion propulsion will allow man to escape the near-Earth solar system and colonize the universe.

The most devastating flaw in O'Neill's book is his general statement that "residents could move in and operate [the colony] comfortably and safely, on the basis of a much lower level of technology than we've grown accustomed to on Earth today." "We need no technology higher than a steam engine," O'Neill says.

This idea of sending human beings into space to devolve and pursue a simple existence goes hand in hand with O'Neill's prediction that colonists will continue to depend upon the Earth for advanced science and art. Those "passionately devoted to one of the sciences, or to music or dance or the visual arts" will go to study on Earth, which will remain the "center of civilization," O'Neill asserts.

If the European colonists who came to the new world 300 years ago had intended to continue to depend upon Europe for scientific and technological breakthroughs, the United States would never be in a position today to even think about going to the stars! The first space colonists will be scientists who tackle the challenges of understanding Earth-forming Titan or developing whole new biologies for non-Earth agriculture. Developing space will require the best minds the human race has yet produced. The new colonies will become the frontier, taking on new problems and pushing science forward to help the Earthlings better understand their universe.

The current issue of *Fusion* outlines some of the most creative ideas for spreading human civilization into space. It is this scientific quality of mind that will be required to colonize space. Curiously, O'Neill, who is himself a high-energy physicist, has written scientists out of the picture in his own space odyssey.

Marsha Freeman

The Kepler-Newton Debate

To the Editor:

The editor's reply to the letter submitted by Charles Sheffield [former president of the American Astronautical Association; "Kepler Versus Newton Versus Fusion," *Fusion*, Sept. 1981] is correct, but the policy issue should be addressed again, in a more hard hitting manner.

Sheffield makes three points. First, he is totally in error in asserting that the "relative roles of Kepler and Newton . . . are not directly relevant to fusion research." Second, he is also entirely wrong in arguing that *Fusion's* treatment of the Kepler-Newton matter is "opinionative rather than factual." Third, he reports correctly that *Fusion's* view of the issue is, "in terms of common belief, a minority . . . view."

From its founding in 1974, the FEF's existence has been premised upon two principal adopted tasks. The first of these two has been to remedy the virtual suppression of development of commercial thermonuclear fusion. The second has been the campaign to introduce a more competent understanding of the relevant physics, Riemannian physics, to the limited numbers of persons and laboratories engaged in the fusion and related efforts.

This twofold commitment has been central to the growth of recognition and influence of the FEF as a scientific association. It was that twofold commitment which is key to the important

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News Briefs


Martin Simon

Day one of the seige at Diablo Canyon: A huge press contingent appeared to outnumber the Abalones.

MEDIA OPEN SECOND FLANK IN ANTINUCLEAR FINANCIAL WARFARE

Just as the Abalone Alliance-led demonstration against California's Diablo Canyon nuclear plant fizzled in mid-September, the antinuclear media launched a campaign of lies against alleged safety problems at Pacific Gas and Electric's newly licensed plant. Part of a broader spate of articles about phantom hazards at some 60 U.S. nuclear plants, the press campaign was the second flank in the new attack on nuclear energy by austerity-minded Wall Street investment banks. (For details of the financial warfare that is choking many U.S. nuclear projects in various stages of completion, see Nuclear Report, p. 18.)

The *New York Times* set the tone with a front-page article on Diablo Canyon Oct. 1, quoting extensively from Peter A. Bradford, a Carter appointee on the Nuclear Regulatory Commission. The *Times* claimed that the NRC was now investigating the plant's five safety systems top to bottom, in line with the environmentalists' charges that the plant is hazardous because of nearby earthquake faults. An angry spokesman for PGE told *Fusion*, however, that the NRC was not undertaking any new review of the plant, whose temporary license it approved Sept. 21; the utility was only suspending fuel-loading to evaluate the seismic support system for the plant's cooling system—a single system.

The press also blew completely out of proportion the fact that the original computer stress analysis test on the pipes was invalid because it was mistakenly run on Diablo Canyon's unbuilt unit 2. However, the two Diablo Canyon plants are mirror images; the blueprint for both is a transparency that is simply turned over to show the other plant. As of this writing, the utility is redoing the computer stress analysis, a three-week job, and at most may have to add more pipe hangers. In July, the government's Atomic Safety and Licensing Appeals Board ruled that the plant is in no way imperiled by the earthquake faults, and there has been no change in that analysis.

Dr. Homi N. Sethna: Soft energy sources are cost-ineffective.

FUSION IS 'ULTIMATE SOLUTION,' SAYS INDIA'S ENERGY CHIEF

"Fusion energy will be the ultimate solution to man's energy problems," the chairman of India's Atomic Energy Commission, Dr. H. N. Sethna, concluded in an address before the International Conference on Women Engineers and Scientists in Bombay, Sept. 8. Reviewing the full sweep of energy sources proposed for the developing sectors, Sethna remarked that "our per capita energy consumption can never reach the levels of the advanced countries if we plan our energy strategy based on fossil fuel alone." He dismissed the so-called soft energy sources being touted for the Third World as "extremely dilute" in form and therefore inefficient and cost-ineffective.

The previous week, in an unusually candid address, Sethna had criticized those in the West who argue that the developing nations should not follow the "mistaken path" of scientific and technological development.

SECRETARY HAIG ENDORSES WEST GERMAN 'GREENIE' MOVEMENT

During a visit to West Berlin in mid-September, U.S. Secretary of State Alexander Haig gave backing to the environmentalist-disarmament movement, which is trying to bring down the government of Chancellor Helmut Schmidt. Haig's arrival triggered a 30,000 to 50,000 person anti-American demonstration, the firebombing of the U.S. consulate in Frankfurt, and the attempted assassination of a top American Army general—all purportedly in protest of America's military policy. Haig, however, commented that the "Greenie" peace movement was the product of "an objective assessment by honest people." Aboard his aircraft on the way back to the United States, Haig told the press that the tens of thousands who demonstrated during his visit against the American decision to deploy missiles in Western Europe in fact reflected a broader antinuclear sentiment that, combined with environmental concerns, has become a major factor in political decisions.

RALLY SUPPORTS WEST GERMANY'S BIBLIS NUCLEAR PROJECT

A political rally to support the Biblis nuclear power project in West Germany Aug. 27 drew 150 participants and remoralized the area's pronuclear movement, which has been under continuous attack from the Greenies. Biblis is the site of the largest nuclear reactor complex planned in West Germany. However, its construction has been held up repeatedly by violent antinuclear demonstrations, raising questions as to whether it will ever be completed.

Organized by the European Labor Party (ELP), the rally included town mayor Seib, local politicians from the Social Democratic and Christian Democratic parties, and more than 30 trade union representatives. ELP chairman Helga Zepp-LaRouche, the main speaker, called for "two, three, many Biblises!" and said that "the time has come to wipe out the cultural foundations of the environmentalist movement—the liberal education reforms of the last 12 years, which have replaced the study of natural sciences with sociology, psychology, and the other 'ologies.' "

The meeting was attended by representatives from the Committee for Cattenom, a cross-party alliance in France that includes the FEF. The group was formed last spring to protect the 5,200-MW Cattenom project in Lorraine from shutdown by the Socialist government of François Mitterrand.

NSIPS

West Germany needs "two, three, many Biblises," ELP Chairman Helga Zepp-LaRouche told a rally.

CHINA USES FORCED ABORTIONS FOR POPULATION CONTROL

Thousands of women who are pregnant for the second or third time are being forcibly strapped onto operating tables and subjected to mandatory abortions in the People's Republic of China, according to reliable press accounts. The Hong Kong-based *Zhenming Daily*, a procommunist newspaper that opposes Chinese premier Deng Xiaoping, reported in August that the forced abortions were ordered at the highest level of the Communist Party in Guangdong province. In that province alone, the newspaper reported, 47,000 women have been required to have abortions since April 1981. Nationally, the Peking regime has instituted new laws forbidding couples from having more than one child, in order to attain the goal of zero population growth by 2000.

Peking's population policy was given an unqualified endorsement by the 1981 annual report of the World Bank published in August. Last year, the report of the Independent Commission on International Development Issues, known as the Brandt Commission, singled out China as the model for other countries to follow: "Those who have pursued such [birth control] programs vigorously have registered considerable success. China, which already has 1 billion people, has in the course of the 1970s reduced its rate of growth from 2.3 percent to little more than 1 percent. It aims at zero growth by the year 2000." The World Bank's annual report maintains, contrary to the news from China, that the birth control program is based on "disincentives that are mostly social."

LOUSEWORT LAURELS TO 'PROFESSOR OF THE YEAR'

This month's Lousewort Laurels go to Mary Eleanor Clark, who was named "Professor of the Year for 1981" by the Council for the Advancement and Support of Education. Clark, who teaches biology at San Diego State University and has written a popular textbook in her field, maintains that biology teaches that "no population can long exceed the carrying capacity of its environment." In a recent interview, Clark states that industrial society has "become so dependent on technology that we have lost our adaptability. . . . We have become its servants rather than its masters." As a solution, she proposes that we foster cultural diversity so that if "our Western-type high-technology

You read it first in Fusion! *Above, the Nov. 1979 article that described the sudden classification—and stultification—of U.S. work on fast liner fusion, and Dr. Leonid Rudakov, whose 1976 U.S. talk was covered exclusively in* Fusion.

culture" fails, we can become Eskimos, Bushmen, or other jungle tribes in order to survive.

SOVIET SCIENTISTS REPORT BREAKTHROUGH IN FAST LINER FUSION

Soviet fusion researchers have achieved a major breakthrough in the development of fast liner fusion systems: For the first time, according to informal reports to American scientists, the Soviets have successfully imploded a hot, dense plasma using a fast liner system. In this approach to fusion, electrically conducting, hollow cylinders, which greatly amplify the energy density of electromagnetic energy, are used for heating a plasma to fusion conditions. In the Soviet experiment, the initial plasma conditions before implosion were reported to be 10^{17} per cubic centimeter density and 11 million degrees Kelvin temperature. The liner was reported to have achieved an implosion velocity of 10^6 centimeters per second.

Magnetic fields of several million gauss have been previously generated by the fast implosion of hollow metal cylinders. The challenge has been to produce a hot, dense plasma and keep it within the inner cylinder, or liner, during the implosion. The extreme magnetic fields produced during implosion will then compress and heat the plasma to fusion conditions. The energy produced can be used to directly run a fusion reactor or, as is being researched by Dr. Leonid Rudakov in the Soviet Union, the energy from the fusion plasma can be used in the form of soft X-rays to implode a second, high-gain inertial confinement fusion target pellet.

GOVERNMENT DECLASSIFIES SOFT X-RAY MAGNETIC APPROACH

A U.S. government scientist has for the first time commented on the use of soft X-rays from a magnetic plasma to implode inertial confinement fusion targets, a line of research recommended by *Fusion* for more than two years. J. P. VanDevender of Sandia National Laboratories, the U.S. group that is pursuing ion beam pellet fusion, commented on the approach in his presentation to the Fourth International Topical Conference on High-Power Electron and Ion-beam Research and Technology in Palaisea, France June 29 through July 3.

In an abstract of "PBFA-1 Pulsed Power Driver for Inertial Confinement Fusion," Dr. VanDevender et al. state: "In the pulsed power approach to fusion, the electromagnetic energy of a pulsed power generator is converted to the kinetic energy of an imploding foil, which produces X-rays to drive the target."

SOVIET SCIENTIST CITES FUSION MAGAZINE ON TARGET DESIGN

The subject of fusion targets driven by soft X-rays was also taken up at the conference in Palaisea, France by Dr. Leonid Rudakov, the Soviet electron beam scientist whose 1976 U.S. talk on the use of soft X-rays in inertial confinement—and its subsequent classification by the U.S. government—was covered exclusively in *Fusion*. According to U.S. scientists present at the French conference, Rudakov showed a slide in which an electron beam is converted to electromagnetic energy via a reverse diode. Then the electromagnetic energy implodes a hollow, cylindrical metal liner onto a plasma. In this way, very strong magnetic fields are generated, compressing the plasma to high densities and temperatures. The magnetically compressed plasma then produces soft X-rays, which impinge on an ordinary inertial fusion pellet. The pellet is ablatively imploded, in such a way that an overall fusion energy gain is achieved.

According to several U.S. scientists, when Rudakov was asked about the details of these "complicated, classified pellets," he smiled and said, "I read about it in *Fusion* magazine."

The World's First Breeder Reactor

Scotland's 'Nuclear Park' at Dounreay

Managing editor Marjorie Hecht spent a week visiting Scotland's energy and industrial sites in June as the guest of the Scottish Development Agency. The SDA is a government agency set up in 1975 to encourage new industry in Scotland, both domestic and overseas firms. In addition to the North Sea offshore oil industry, Scotland's main new areas of development are computer-electronics and medical research.

* * *

Scotland may bring to mind heather, whiskey, and kilts—but not nuclear power. Yet this largely rural country about the size of the state of South Carolina, with a population just over 5 million and plenty of hydro power, oil, and gas, generates 25 percent of its electricity from nuclear energy.

Even more surprising, Scotland has one of only three operating breeder reactors in the world (the others are in France and the Soviet Union); Scotland had the first breeder reactor in the world (1962); and Scotland was the first to supply power from a breeder reactor to a national electric grid (250 MW in 1974).

Having watched the U.S. Clinch River Breeder Reactor project slip into limbo over the past few years, I was intrigued, and I happily accepted the invitation of the Scottish Development Agency to tour the Dounreay Nuclear Power Development Establishment and see the nuclear breeder program.

I wanted to learn more about breeder technology. And I hoped to figure out why the United States, which had promoted the concept of Atoms for Peace back in the 1950s, and which had mobilized the nation behind the development and export of nuclear technology, has no breeder program today, while Britain, which has never had a nuclear export policy, has perfected this advanced nuclear technology in Scotland.

Dounreay Nuclear Power Development Establishment

An overhead view of Dounreay. In the background is the Dounreay Fast Reactor (the sphere), the world's first breeder reactor. The group of buildings in the foreground houses the Prototype Fast Reactor and related operations.

Dounreay: A 'Nuclear Park'

The Dounreay Nuclear Power Development Establishment is in Caithness, a farm area on Scotland's rugged north coast, on a site that was an airfield during World War II. In 1954, the United Kingdom Atomic Energy Authority (UKAEA) selected Dounreay as the location for an experimental breeder reactor, or *fast reactor*, as it is known in Britain. Four years later, the Dounreay Fast Reactor was completed, and it began to produce a small amount of electricity for public consumption in 1962, reaching 15 MW by 1963.

In 1965, construction began on the Prototype Fast Reactor (PFR), conceived as an engineering model for commercial breeder reactors. The PFR began to produce significant amounts of electricity in 1974, feeding 250 MW into the national power grid. The total cost of constructing the PFR, from 1965 to 1974, was £45 million, approximately $90 million.

The next step is a 1,200 MW commercial breeder, the CDFR, or Commercial Demonstration Fast Reactor, for which Dounreay's nuclear engineers think they are technically and scientifically ready, having thoroughly tested all areas of operation and safety on the PFR, but whose future is uncertain.

In the next few years, however, Dounreay could become what may be another world first—a "nuclear park," where the nuclear fuel cycle is completed on one site, from enriching and fabricating uranium, to reprocessing spent fuel, to breeding new fuel in a fast reactor, and, of course, producing nuclear power in the process.

For this pronuclear American, the visit to Dounreay was an exciting view of advanced nuclear technology. Dounreay, in fact, is unique in that visitors are able to tour the PFR, and about 30,000 persons visit the site each year. In addition, Dounreay has a Fast Reactor Training Centre, the only one in the world, which gives hands-on training to about 2,000 engineers and technicians annually.

What Is a Fast Reactor?

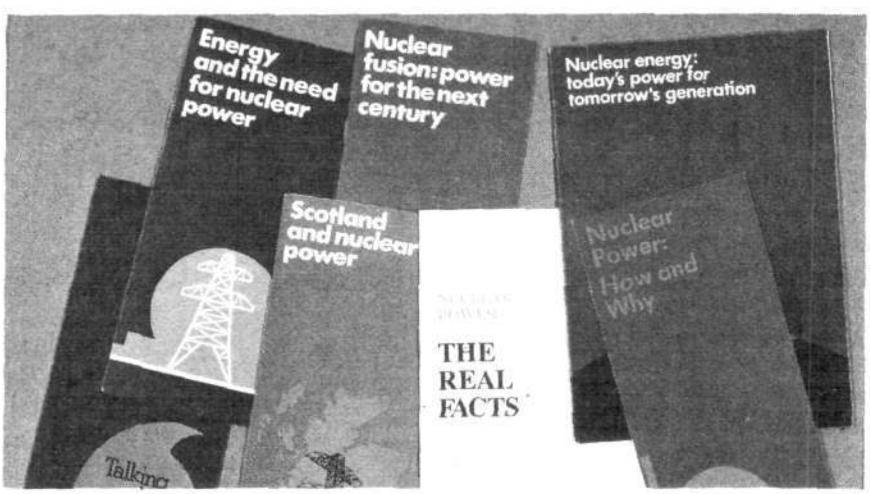
Fast reactors burn uranium fuel many times more efficiently than ordinary thermal reactors. Conventional nuclear reactors burn only about 2 percent of the uranium in their fuel rods, producing plutonium as a waste by-product. In these reactors, the neutrons from the nuclear fission process are slowed down, or moderated, using water or graphite, to cooler, thermal temperatures.

In a fast reactor, or what Americans call a breeder reactor, the neutrons from the fission process are not moderated. As a result, fast reactors can burn the plutonium produced in thermal reactors as fuel and can convert the depleted uranium fuel (otherwise nuclear waste) into new plutonium fuel. At the same time, fast reactors produce energy to feed into the power grid.

As the UKAEA literature spells out, with a mix of fast reactors and light water or other conventional nuclear reactors, nearly all the uranium fuel would be recycled; waste would be minimized. (Of what we call nuclear waste, depleted uranium fuel, 97 percent would be recycled and only 3 percent would have to be disposed of.) Furthermore, because fast reactors can produce 50 to 60 times as much useful energy from crude uranium as can thermal reactors, just 500,000 tons of crude uranium oxide, would be enough to generate plenty of electricity for the UK for several hundred years—"long after the last drop of oil has been won from the North Sea."

In the UK overall, nuclear energy provides about 12 percent of the electricity, and current plans are to bring the nuclear share up to 33 percent by the year 2000.

The safety parameters for a fast reactor are the same as those for a conventional nuclear reactor. The highly radioactive liquid waste from the reprocessing of fast reactor fuel is not significantly different from the waste from other nuclear reactors, and the same handling applies.



Despite the fact that the antinuclear World Wildlife Fund is headed by England's Prince Philip, England and Scotland have not suffered from news media that portray nuclear power as a monster, nor is there a large greenie lobby.

Here are some of the excellent pamphlets published by the UKAEA on nuclear power. "The Real Facts" pamphlet reprints an entire antinuclear pamphlet put out by the Ecoropa organization and refutes each statement point by point. Also note the pamphlet on fusion energy, which is mentioned in all the UKAEA materials as the energy source of the 21st century.

Sodium Cooling

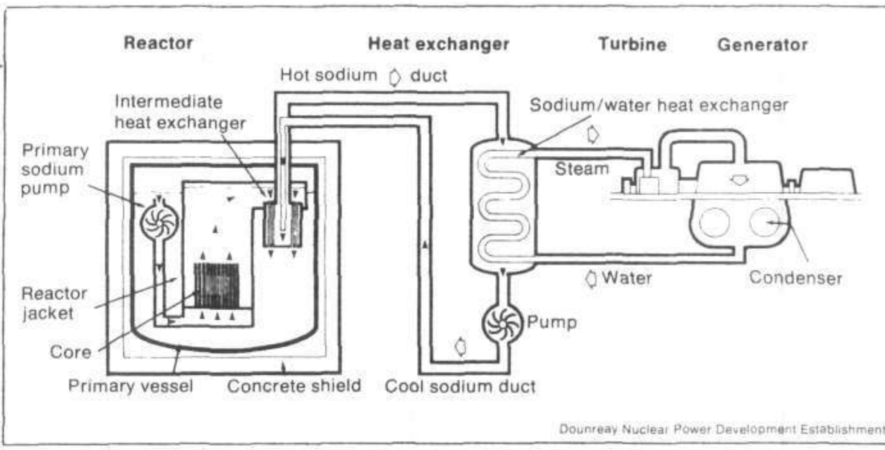
The Prototype Fast Reactor is cooled by liquid sodium. A silver-gray metal which can be cut with a knife at room temperature and which melts at 98° C, sodium removes heat from the reactor core 10 times as efficiently as gas or water. Much of the early research at Dounreay was on the handling of liquid sodium. From this work, researchers learned that it is important to keep the sodium free from impurities, and a soundwave system is used to monitor the coolant to see that impurities, particularly oxides, don't rise above a few parts per million.

The reactor vessel, 15.2 meters deep and 12.2 meters in diameter, is located on an underground level, suspended in a concrete vault and enclosed in an insulated jacket (see diagram).

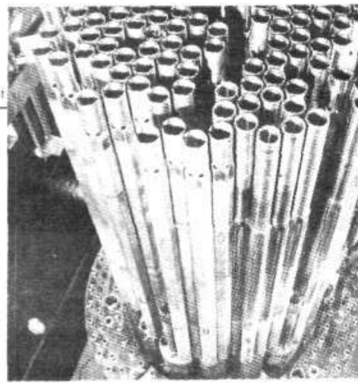
The fuel and breeder assemblies, hexagonal-shaped rods, are placed on a grid at the base of the vessel (see photograph). The reactor core's inner zone consists of fuel pins that contain pellets of uranium oxide and plutonium. The outer zone consists of "blanket" pins of depleted uranium. The neutrons produced by the fission process in the inner zone are absorbed by the blanket pins and converted into plutonium.

Graphite-filled steel tubes around the fuel assembly provide shielding to reduce radiation levels in the outer part of the vessel. A rotating shield on the roof of the reactor vessel is used for refueling, which occurs about every seven weeks.

The fuel can be examined using remote handling before and after reactor use in "hot cells," or what Dounreay calls "caves," located in the PFR building. The caves are concrete boxes with lead glass windows and robotic arms and hands that allow researchers to pick up and examine the radioactive materials without any



The primary liquid sodium system in the PFR transfers heat from the reactor to intermediate heat exchangers. From there a secondary, separate sodium cooling system carries the heat to water heat exchangers, which produce steam for the power plant turbines. Inset: A model of fuel and breeder assemblies.



danger. When Dounreay is expanded to become a nuclear park, new fuel and spent fuel will be transported for fabrication and reprocessing—and waste will be buried—all on site through a system that connects up to the caves.

Although the fuel processing for the PFR's predecessor, the DFR, was done at Dounreay, The PFR's fuel is prepared at a plant in Windscale, Britain, and transported in a specially constructed ship up the coast to Dounreay. In the future, however, fuel will be fabricated on site.

There are two sodium coolant systems. In the primary system, the liquid sodium surrounds the reactor core in a pool. The primary sodium pump pumps hot sodium out of the reactor vessel to the intermediate heat exchangers (see diagram). Then the primary sodium returns, much cooler, back into the pool around the reactor. The secondary coolant system is nonradioactive and completely separated from the primary sodium coolant by the reactor jacket. The secondary sodium carries the heat from the intermediate heat exchangers to the water heat exchangers, which produce steam (at 1,000°F). The steam then turns a conventional turbine and generates electricity—250 MW.

The Next Step

Since the 1950s, the UKAEA has planned and conducted design studies for a commercial demonstration fast reactor (CDFR) of 1,000 to 1,200 MW, and the PFR has provided more than adequate experience to go ahead with such a project. Yet the government will probably take 20 years to build it, even though, unlike the situation in the United States, everyone agrees the fast reactor is ready for commercialization. (France, it should be noted, with much less direct fast reactor experience, will soon have its Super Phenix breeder on line.)

Why the delay? And why are there no plans for exporting fast reactor technology? These were my main questions after touring Dounreay. The delay just didn't fit with the very positive nuclear literature put out by the UKAEA. For example, a pamphlet on "Energy and the need for nuclear power" dated Jan. 1981 argues that nuclear power, including fast reactors, is essential for raising world living standards, that 70 percent or more of electricity in many countries could be generated by nuclear, and that "energy from the sun, wind, waves, and tides . . . will not offer relief on a large scale before the end of this century."

Nor does the delay fit with the philosophy of the Scottish Development Agency, which is devoted to using the Scottish tradition of science and engineering to rejuvenate the economy. Dounreay, in fact, is an example of how advanced technology has brought education (a new technical college), jobs, and an enriched cultural environment to a rural area of shepherds, crofters, and fishermen.

It is also clear that the general population is pronuclear, and there is not a well-heeled greenie movement promoted by the news media, as you find in the United States.

The technical secretary of the Fast Reactor Training Centre answered my question on the CDFR somewhat unhappily. First, he said, the government has to hold a public inquiry, which they plan to do in 1984-85. Then, if all goes well, they'll start construction by 1987-88. There will be another eight years or so in construction, and another ten years or so to get operating experience, and then—about 2006, by my calculations—Britain might consider starting a full commercial fast reactor program.

The reason for the late start on CDFR hearings, the Dounreay official said, is that the government is putting priority on assessing pressurized water reactors (PWRs) as replacements for the standard advanced gas-cooled nuclear reactor used in Britain. "There's a limitation on the number of people who are qualified to do the basic safety assessments required for nuclear plants, and the government feels it is more important to put these people to work on the PWR. The fast reactor program doesn't see it that way," the Dounreay official said.

As I shook my head in disbelief, he shrugged and added, "Well, at least we're not quite at the stage Jimmy Carter brought your breeder program to."

—Marjorie Mazel Hecht

Interest Rates Are Killing The U.S. Nuclear Industry

Nuclear power development in the United States is faring worse under the pronuclear Reagan administration than under its antinuclear predecessor. But now financial warfare rather than antinuclear regulation is to blame.

The Federal Reserve's high interest rate policy not only has ruled out capital investment in new nuclear power plants, but also is forcing the cancellation of plants now under construction, whose completion was held up by intervenor hearings and court battles during the Carter administration.

This retrenchment is being welcomed and encouraged by the utility bond underwriters on Wall Street, who argue that depressed economic conditions don't warrant any more nuclear power plants. Last spring, a bearish-on-nuclear Merrill Lynch issued a report on the outlook for nuclear power, predicting that 18 plants under construction were likely to be canceled over the next year. The report commented that early termination of the projects would in a number of cases strengthen the financial rating of the parent utilities.

The argument that weak demand doesn't justify new nuclear capacity is now pervasive. But the connection between nuclear power and the economy is more complex. The shutdown of U.S. nuclear power development will in fact ensure a permanent depression in the U.S. economy because, historically, it has been the availabiltiy of cheap electricity that has created demand and stimulated economic growth, not the other way round.

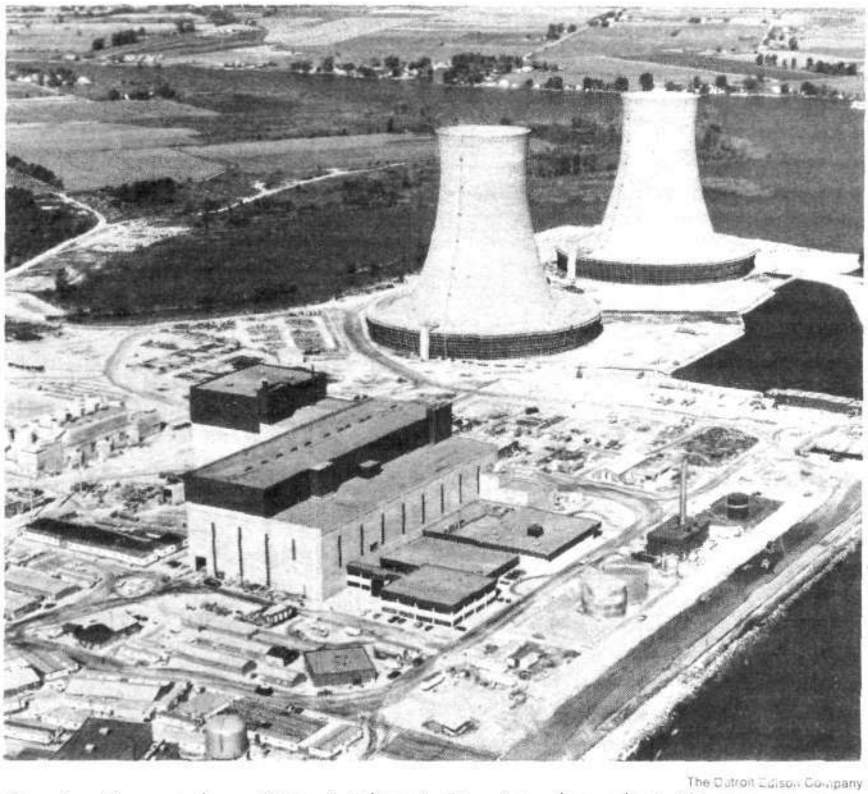
Despite the howls about the rising costs of nuclear power, nuclear-generated electricity (including amortized construction costs) is still the cheapest, even though environmentalists' interventions have sharply raised construction costs.

For the United States and other advanced-sector nations, the now-in-progress shutdown of nuclear power will mean overstretched electricity grids and power blackouts. For the developing countries, whose successful industrialization depends on nuclear exports from the advanced countries, the consequences are those predicted by the *Global 2000 Report*—massive depopulation.

The Facts

A preliminary review of the plight of nuclear power in the United States, gathered in late August, showed:

- No credit is available to utilities for the construction of new nuclear plants; on already started projects, financing costs are rising prohibitively, and underwriters are demanding early principal repayment and otherwise cooperating in challenges to the bonds of nuclear utilities.
- Inflation, intersecting the 12-year construction time now typical for nuclear plants, has driven construction costs alone to more than $2 billion per unit in some cases (compared with a typical $300 million cost for a 1,000-megawatt plant through the mid-1970s).
- Interest costs alone are now approaching two thirds of the total cost of some nuclear projects (construction and financing). Bond rates on existing projects have "floated" up two and a half times since construction began in a number of cases.
- Wall Street utility analysts, insisting that falling demand will eventually eliminate the need for additional nu-



The Detroit Edison Company

Construction work on Detroit Edison's Fermi nuclear plant, 85 percent completed, may be halted because of a court order that has barred the utility from issuing bonds to cover final construction costs.

clear starts, are advising investors against investing in nuclear utilities.

• No new nuclear plants have been started in the United States for almost three years, no utility company is planning any new starts, and a number of existing projects are threatened with cancellation.

• U.S. nuclear exports to developing sector countries are at a standstill, despite talk by the Reagan administration of expediting the export process.

Midwest Brownouts?

The financial squeeze on nuclear power is already taking its toll, particularly in the older industrial regions of the country. In what could set a national precedent, Detroit Edison was blocked by court order in August from issuing $1.9 billion in securities needed to continue construction on two plants, the Fermi nuclear plant near Monroe, Mich., and a coal-fired plant near St. Clair. The Court of Appeals stay was instigated by the State Attorney General's Office and the Michigan Citizens Lobby, an antinuclear consumer advocate group.

"We're contending that Detroit Edison hasn't shown that the Fermi plant is needed," Assistant Attorney Patrick Devlin said in an interview. This argument is premised on projections of reduced electricity demand from consumers and the state's devastated auto and auto feeder industries.

Detroit Edison contends that it needs both plants to maintain adequate reserve margins and to enable it to retire old, inefficient capacity. The two plants are expected to account for 20 percent of Edison's generating capacity by 1985. However, if Detroit Edison can't issue the securities this fall, the utility says it will be forced to shut down both projects because of cash flow problems; 6,000 jobs would be lost and the future completion of the projects jeopardized. The Fermi plant is already 85 percent completed, scheduled to begin operating in 1983, and Detroit Edison has invested $1.25 billion in the project.

On Aug. 14, the Michigan State Supreme Court upheld the lower court stay barring Detroit Edison from issuing securities, and in mid-October, the case goes back to the Court of Appeals. Devlin will argue for the State Attorney General's office that the Detroit Edison plants and Consumers Power's Midland nuclear project should all be terminated now, because they are too costly and their power won't be needed when the projects are completed. The defendant in the case is Michigan's Public Service Commission, which had previously approved both utilities' bond sales.

National Ramifications

Devlin predicted that the Michigan case would have ramifications for nuclear projects across the country. The Fermi plant is but one of numerous nuclear projects whose costs have been wildly inflated by regulatory delays and environmentalist challenges—by as much as 10 times the original projection. These projects are now being challenged "on economic grounds" by a strange alliance of frustrated consumerist groups, environmentalist think tanks, and Wall Street bond houses.

In a number of cases—the challenge to the Niagara Mohawk plant in upstate New York, for example—the consumer advocates are being advised by lawyers from the National Defense Fund and Natural Resources Defense Council who have switched their litany from the hazards of nuclear energy to its allegedly high cost.

But the line that nuclear power is not cost-effective or needed originates with the Wall Street underwriters, whose projections are tailored to a future zero econmic growth under usurious interest rates. The financial managers are assuming that U.S. electricity consumption is going to grow only 2 to 3 percent henceforth, not the 4 to 5 percent per year projected when many of these plants were started.

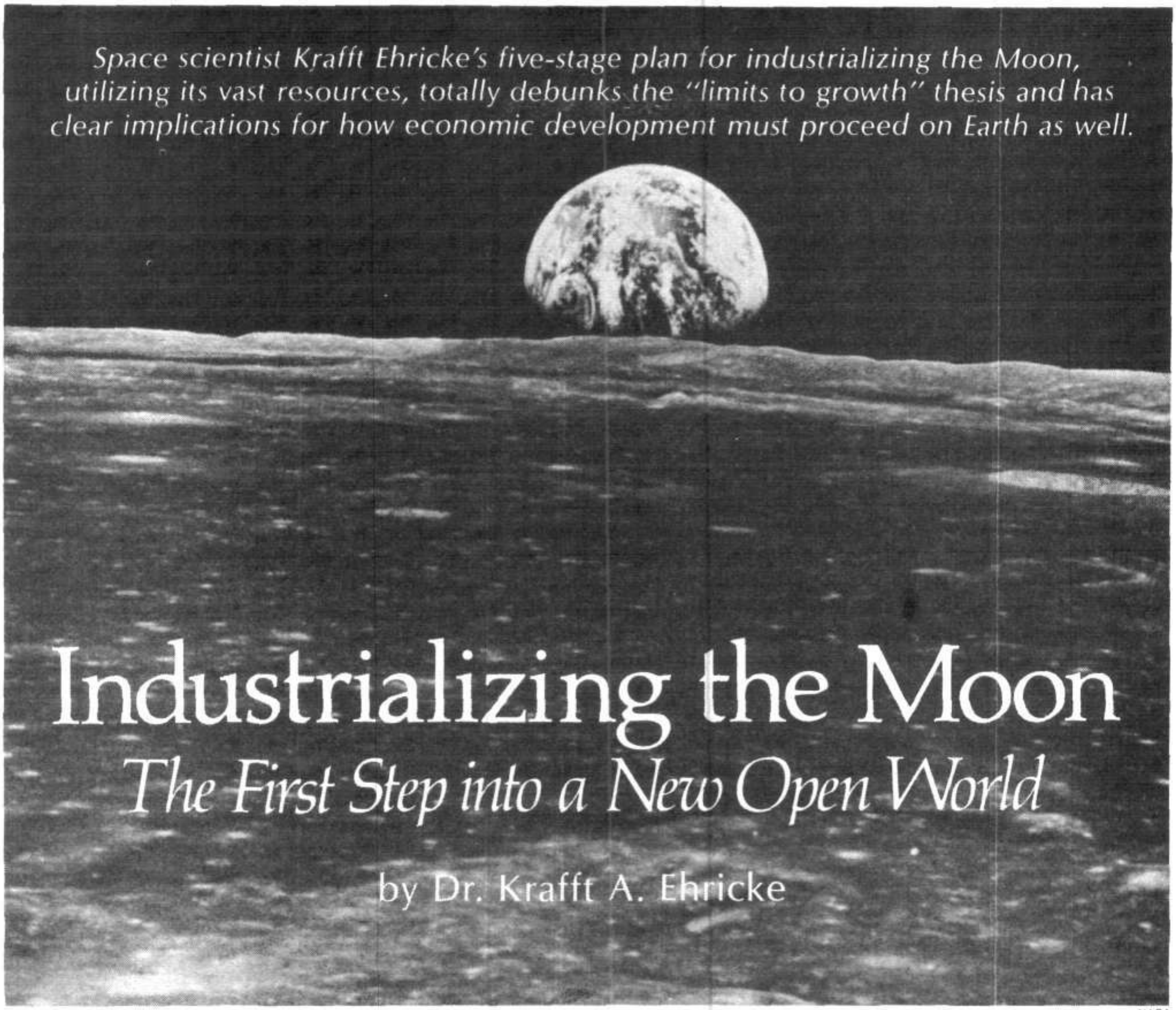
Their argument that nuclear is not cost-effective is premised on the assumption of 10-year to 12-year construction times for nuclear plants and double digit inflation as inevitable.

"Nuclear power has never made sense from the standpoint of the stock or bond holder," one utilities analyst commented. "First, you're tying up large amounts of capital for a long time. And once the plant starts operating, the fuel savings accrue to the customers, not to the investor."

This kind of thinking, which is applied to all capital-intensive projects, has undermined capital investment in the United States; it is at the root of the technological obsolescence that is destroying the American economy.

As for the ratepayer groups who are calling for the shutdown of nuclear projects for economic reasons, they have simply been duped into demanding future power blackouts.

—Lydia Schulman



Space scientist Krafft Ehricke's five-stage plan for industrializing the Moon, utilizing its vast resources, totally debunks the "limits to growth" thesis and has clear implications for how economic development must proceed on Earth as well.

Industrializing the Moon

The First Step into a New Open World

by Dr. Krafft A. Ehricke

NASA

PART 1

IT IS FORTUITOUS that the bridge from the Earth into the cosmos has two strong and, in the inner solar system, unique piles near our planet. One is the cosmic harbor in near-Earth space, behind the breakwater of a strong magnetic field, which protects the space region from solar storms, offering sheltered orbits for habitats, bases, and factories. The other is a planetlike body, only three travel days or less away from Earth. The Moon resembles other accessible surfaces in the solar system—Mercury, Mars, the outer planet satellites, and larger asteroids—much more than Earth does and, therefore, represents a virtually ideal proving ground for developing and operating new technologies: It is the logical cradle for the cosmic birth of human civilization.

The road to complete development of cislunar space leads over the Moon. Lunar and cislunar development are literally a prerequisite for a civilization that must eventually be able to ensure a high quality of life for 11 to 12 billion people. Mechanically speaking, since all living organisms are work-performing mechanisms, physical and biological laws demand an Open World as the condition for viability. An Open World is characterized by adequate source-sink systems and environmental latitude. The Sun is an adequate energy source for photosynthetic technology; nuclear energy, one notch closer to the ultimate source of primordial energy, is an adequate source for human—that is, for information metabolic—technology (Ehricke 1971, 1979).

The ultimate sink is space in either case. Materials are recycled completely by biotechnology, which, by itself, is limited to one planet, thereby also solving the sink problem. Information metabolic technology uses the entire periodic system and more, which makes recycling not possible. Neither offers the terrestrial environment sufficient latitude in the long run. Both material and environmental reasons require a larger environment. Therefore, humanity, after having learned to manipulate natural laws technologically, rapidly approaches the threshold of a new Open World, encompassing the entire Earth-Moon system to begin with.

The Moon offers access to industrially valuable raw materials in a shallow gravitational well. Their utilization in the process of developing cislunar and lunar space will eliminate high launch costs from Earth. To utilize this advantage, initial Earth-launched capital equipment and associated infrastructure must generate lunar products not only of superior quality but of many times the imported mass. This requirement can be readily met, but not if a vast effort has to be invested first in the construction of a large orbiting habitat out of imported materials before other lunar materials that must be transported there can be processed.

This course would make about as much economic sense as first constructing an artificial Miami Beach "under glass" at Prudhoe Bay before beginning to pump oil.

The lunar surface itself offers excellent opportunities, as well as protection against micrometeorites and radiation, for constructing habitats on the spot, enlarging them, and enhancing their interior level progressively, concomitant with the overall lunar economic growth.

In the past, human growth could unfold in a monoglobal framework. In the future, human civilization needs to be polyglobal. The Moon is the first step: It alone is large enough to support a civilization (almost the combined area of North and South America) and to underwrite it with a strong industrial economy based on highly advanced nuclear, cybernetic, biotechnical, and material processing technologies, ultimately turning large parts of the Moon into a lush oasis of life, capable eventually of exporting even foodstuffs, at least to orbiting installations if not to Earth.

Developing the Moon's Resources

In a paper published in 1972, I outlined the "extraterrestrial imperative" facing the human species:

> Overshadowed by the limitations of the terrestrial environment, the scenario of world development will undergo fundamental changes in the next 30 years. But the need for resources will continue to grow. Therefore, the emphasis on opening new environments to industrial operations will grow. Since environments which are removed from the biosphere answer both the need for continued industrial growth and for reducing the industrial burden on the biosphere, the opening of extraterrestrial environments will become increasingly attractive, commensurate with economic viability.
>
> Thus, one of the fundamental changes in the world development scenario will be the transition from the classical closed-world to an open-world development model. The open world adds open-space and lunar-type environments to the terrestrial environment. The nearest of the second group is our Moon (1972a).

The conclusions of this paper remain unchanged. They were adopted (though never acknowledged) ever more widely over the 1970s, as the falsehood of the precepts of limits to growth gradually became apparent.

A list of the mineral resources available on the Moon, compared with their abundance on Earth, is presented in the accompanying table. The Earth has enhanced concentrations of metals and other elements, created by megayears of tectonic and biological processes. Corresponding ores have not been found on the Moon, nor are they likely to exist anywhere there to nearly the same extent, if at all, because of the absence of comparable tectonic dynamics, of water, and of life.

However, the average, or background, abundance of several elements is higher in lunar materials than in average terrestrial rocks. Moreover, regions of higher metallic or other elemental abundance do exist (metallogenic or mineralogenic provinces). For example, the bright lunar highlands are about twice as rich in aluminum than the dark mare plains. The plains, in turn, are much richer in iron, titanium, manganese, chromium, magnesium, and some other elements. Within the maria, their relative abundance varies also. For still other elements—sodium, phosphorus, and hydrogen—the differences observed so far are too close to call. The data for the still more rare accessory elements are uncertain.

Just as on Earth, it is obvious that the extraction of materials of low concentration is comparatively more difficult and time consuming than the extraction of rich deposits. Therefore, industrial feedstocks, or products using such elements, will be avoided initially. In time, progressively lower concentrations can be utilized.

Initially, the more abundant elements, such as oxygen, silicon, aluminum, iron, magnesium, and titanium will be extracted and processed. Some of these are also unevenly distributed. For example, the southwestern Mare Tranquilitatis, site of the first manned lunar landing, is a titanium province, richer than the other landing sites, but not necessarily the highest concentration on the Moon. It is important to find other as yet undetected areas of enhanced concentration of other industrially important elements.

Lunar Products

It is impossible to review or anticipate the great variety of products that will eventually comprise the Moon's industrial output. They will include raw stock from mining and refining, as well as a vast number of semifinished and finished products.

This second category is comprised of sheet metal and trusses of aluminum, magnesium, titanium, iron, or alloys; castings, bars, wires, powders of pure or alloyed materials; glasses; glass wool; ceramics; refractories; fibrous and powdered ceramics; insulation; conductors, anodized metals; coatings, including almost perfectly reflective sodium coating (since sodium can be freely used on the Moon and in orbits, whereas on Earth it reacts with water and is dulled by oxidation and therefore generally unsuitable); thin film materials; silicon chips; solar cells; entire structures of various metals and alloys for lunar and orbital installations (they do not have to be made weather resistant); compound and fibrous materials; heat shields and insulation materials, as well as radiation shielding materials for space stations; propellant containers; entire orbiting facilities, such as space station and factory modules and liquid lunar oxygen depots; large portions of cislunar and interplanetary spacecraft; and so on.

Where zero-gravity is required for the manufacturing, easily reached facilities are available in circumlunar orbit (CLO) for manufacturing crystal bole, fibers, solar cells, and other special materials and products whose manufacturing requires gravity levels below lunar, which is already low enough for many products. Parts, components, subassemblies, and full assemblies can be integrated in CLO before being shipped to geosynchronous or other distant circumterrestrial orbits by means of electric freighters, whose thrust acceleration and propellant consumption are very low. Eventually, they will use lunar sodium as propellant. Selenians ("Moon people") will readily, and without requiring adjustment, commute between one sixth Earth gravity and weightlessness.

Primary Markets

There are four primary markets available for lunar goods and services:

(1) *Lunar surface.* This market includes domestic demands for lunar industrial and habitational development; science and technology experiments for terrestrial customers; new forms of entertainment for terrestrial television viewers (low gravity, moonscape, and vacuum will permit new special effects and later new sports and cultural activities); and eventually tourism and retirement for the Terrestrians.

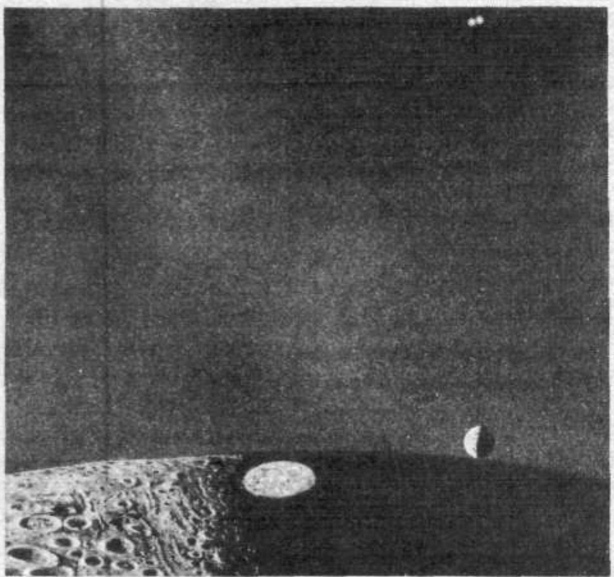
(2) *Geosynchronous orbit.* Geosynchronous orbit, or any other distant circumterrestrial orbit, is accessible from the Moon at a fraction of the energy and cost as from Earth. Geosynchronous orbit in particular may hold well over a thousand service satellites by 2000, satellites that will be virtually indispensable socioeconomically. This market will demand spacecraft servicing; replacement parts; new components; partial or entire new satellites; salvaging and recycling of inoperative systems, sections, components, and elements. In addition, liquid lunar oxygen (LLOX) depots may be established to reduce the cost of manned access or supply deliveries needed from Earth.

(3) *Near-Earth orbit.* Orbiting manufacturing facilities will be likely buyers of lunar raw materials; capital equipment; entire production facilities; oxygen (not only for air but also for water—only hydrogen need then be imported from Earth, which means a large cost reduction); and eventually even some basic foodstuffs (dehydrated, since water is very precious on the Moon).

(4) *Earth.* Earth will be a major market of lunar raw materials; semifinished products; and space-made components in larger quantities and involving larger masses than can be handled economically, if the raw material first has to be supplied from Earth to near-Earth orbital manufacturing facilities. These lunar imports will sustain industries and generate new jobs on Earth.

By goal and conception, lunar industrialization must be intrinsically broad-based and diverse, if it is to last. There is neither time nor money for the wrong agenda. Based on these considerations, and on basic evolutionary logic, the guiding principles of a lunar development strategy can be formulated as follows:

(1) Low-cost access to the lunar surface = low overhead and enhanced capability to provide services in geolunar space, because of low transportation and personnel costs.



Paintings and illustrations by Krafft A. Ehricke

Figure 1
CIRCUMLUNAR LUNETTA SATELLITE
Stage one of lunar development: The Lunetta satellite, an orbiting reflector system, illuminates eternally dark polar regions, and other places during lunar night, from directions that differ from the direction from which they are illuminated by the Sun. Lunetta completes and improves panoramic and cartographic mapping of possible polar landing sites; it also provides light for expeditions should they land at such places, and furnishes night illumination for crews operating on the Moon's far side, where the nights are not illuminated by Earth.

(2) Ample and low-cost energy assurance = high, cost-effective and versatile value generation capacity.

(3) Early self-sufficiency = low import costs, hence low operating costs and enhanced survival capability of lunar personnel.

(4) Industrial flexibility = cost-effective means for increasing the capacity for diversification and adaptability to changes in market demands.

These principles have guided my studies since I called for the broad industrial use of extraterrestrial materials, specifically lunar materials, before NASA in 1971 and publicly since 1969 (Ehricke 1971a, 1969, 1970).

Resource Extraction and Processing

The extraction of lunar raw materials will involve separation and refining. It remains to be determined whether the Moon's material composition changes with depth, in an industrially favorable sense. However, present seismic indications are not promising in this respect—it is unlikely that zones of high content of iron or aluminum, or pockets of nickel deposits, exist at greater depths.

It is fortuitous, on the other hand, that the lunar surface crust already contains many industrially valuable elements. This will permit inexpensive strip-mining, a natural for lunar low-cost productivity. In fact, it is the lunar surface that is relatively richest in hydrogen, nitrogen, carbon, and other light solar elements. As a result of solar wind protons, surface material is being deoxidized, saving man some of the energy-intensive processes involved in reducing lunar crude.

of rock, crushing its crystalline structure and turning it into glass. The spherules can be extracted by mechanical or electrostatic separation for further processing to glass products.

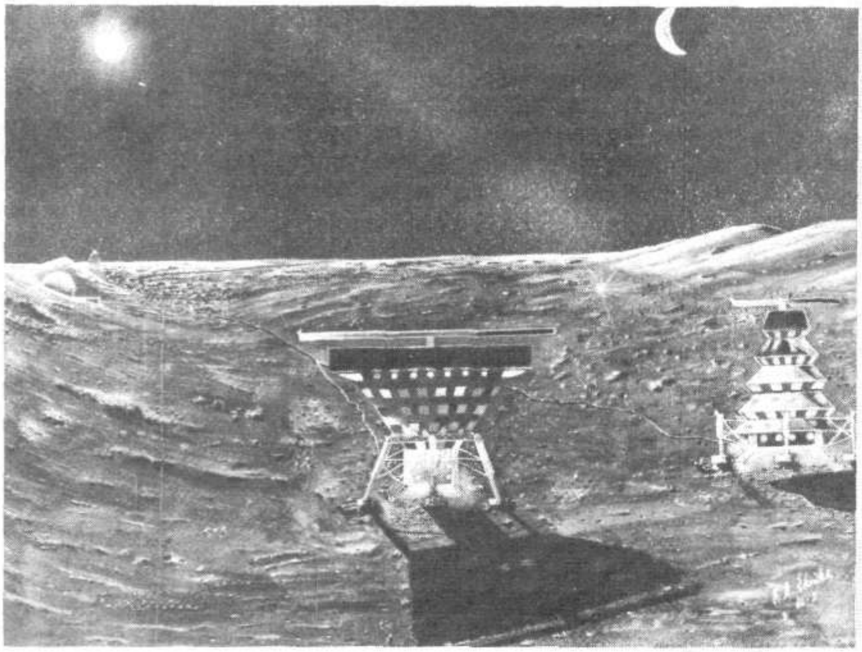
Finally, there is thermal-mechanical separation. Here, elements or compounds are separated centrifugally after partial or complete melting.

All these separation processes are comparatively simple and do not require complex or heavy equipment.

Refining processes using electrolysis, chemical, or thermal methods reduce and also can be used to separate different semimetallic and metallic materials from each other. Electrolysis is used less frequently because of its high energy requirements. The two most important elements for chemical reduction, carbon and hydrogen, are not available in relevant quantities (at least initially), whereas abundant low-cost nuclear energy can be.

Figure 2
A NEW BEGINNING: LUNAR OPERATIONS CENTER

Stage two of lunar development: Two laboratory/habitat modules (with more to follow) are placed on the lunar surface, along with a nuclear power station to serve them (its conical radiator surface is visible in the background). The inverse converging shape of the modules maximizes shielding against corpuscular radiation, optimizes temperature control for placement in equatorial regions, and serves as an umbrella to provide shade in the immediate vicinity of the module.



Pure iron has been discovered in samples returned by Luna 16, from northeast Mare Fecunditatis, and probably is present in other samples. From the magnetic susceptibility of surface material, it may be concluded that some of it contains 0.15 to 0.2 percent pure iron by weight, and possibly also smaller amounts of other metals such as chromium and nickel in pure form. By passing the lunar sand and crushed rocks through a magnetic separator, pure iron particles can be extracted, perhaps as much as 1,000 kilograms (kg) of iron out of 550,000 to 600,000 kg of sand.

Another valuable raw material is the small glass pearls distributed widely in the surface sand. These were generated by the impact of large meteorites and small asteroids. Shock waves of up to half a million atmospheres pressure caused melting and evaporation of large masses

Chemical reduction and basic or acid leach processes do not appear attractive for early lunar industrial operations because of two principal disadvantages:

They are complex, requiring larger amounts of chemicals that must be imported from Earth than do other refining processes. Because of their cost, these chemicals must subsequently be recycled. Lunar industrial material recycling, of course, will be necessary, particularly for imported materials; however, the smaller the number of catalytic and reducing or oxidizing agents that must be recycled, the better.

For electrolysis, the lunar material is melted by nuclear (day and night) or solar (day) processing heat, or electrically. The effects of subsequent electrolysis of the molten material are well known: Oxygen, as well as other electronegative nonmetals, are collected at the anode; metals at

Abundance Rank (Earth)	Element	Average Rocks: Abundance (grams per metric ton of rock)				
			Moon		Meteorites	
		Earth	Highlands	Mare	Metallic Iron	Ordinary Chondrites
1	Oxygen	4.66-4.7×10^5	4.5×10^5	4.2×10^5	—	35.1
2	Silicon	2.27-2.95×10^5	2.1×10^5	2.1×10^5	40	17.8
3	Aluminum	0.81×10^5	1.3×10^5	0.7×10^5	40	1.3
4	Iron	0.5-0.47×10^5	0.49×10^5	1.3×10^5	9.08×10^5	2.51×10^5
5	Calcium	0.36-0.3×10^5	1.07×10^5	0.79×10^5	500	0.14×10^5
6	Sodium	0.28-0.25×10^5	3100	2900	—	6800
7	Potassium	0.26-0.25×10^5	800	1100	—	870
8	Magnesium	0.21×10^5	0.46×10^5	0.58×10^5	300	1.44×10^5
9	Titanium	4400-4500	3000-3200	0.3×10^5	100	640
10	Hydrogen	1400	55-60 (surface layer)	50-55 (surface layer)	—	—
11	Phosphorus	1200-830	500	600	2000	1000
12	Manganese	1000	650-700	1700	300	2600
21	Chromium	90-100	800-900	2500-2700	40	2200
		Uncertain, But Important, Accessory Elements in Lunar Material — Lunar Samples from Apollo 17 (Taurus-Littrow) and Luna 24 (South M. Crisium)				
	Strontium	450-40	90-210		—	11
	Carbon	200	100		1100	0.1
	Chlorine	150-170	20		—	160
	Zirconium	140-170	10-200		8	35
	Vanadium	90-120	10-170		6	64
	Zinc	40-83	—		110	54
	Copper	47-55	—		150	100
	Nickel	35-58	70-180		86,000	1304
	Cobalt	18-28	28-59		5000	500
	Tantalum	2-2.5	0.13-1.3		0.06	0.023
	Tungsten	1.0-2.1	—		—	0.14
	Silver	0.008-0.08	—		3	0.05
	Gold	0.0002-0.004	0.0002-0.0027		1.8	0.16

TERRESTRIAL, LUNAR, AND SOME METEORITIC ABUNDANCES

The values given in this table show trends but do not tell the whole story. For example, in the top surface layer of rock pieces (breccia) fragmented by meteoritic impact and abrasion, the hydrogen content may be as high as 120 grams per ton, whereas in the deeper layers of mare basalt hydrogen is practically nonexistent.

The elements are oxidized and occur in mineral compounds in essentially three types of lunar rocks, all igneous (i.e., originating from molten mixtures of minerals): mare basalt, highland anorthosite, and norite (gabbro). Most of the basalt minerals are pyroxene and olivine; most of the highland rocks contain feldspar.

Mechanically, lunar crude occurs as fines, breccia, large pieces of rock, and solid lunar rock. Solar wind protons striking the unprotected surface generate a small portion of hydrogen in the uppermost layers. Minute amounts of other light elements from the Sun are captured.

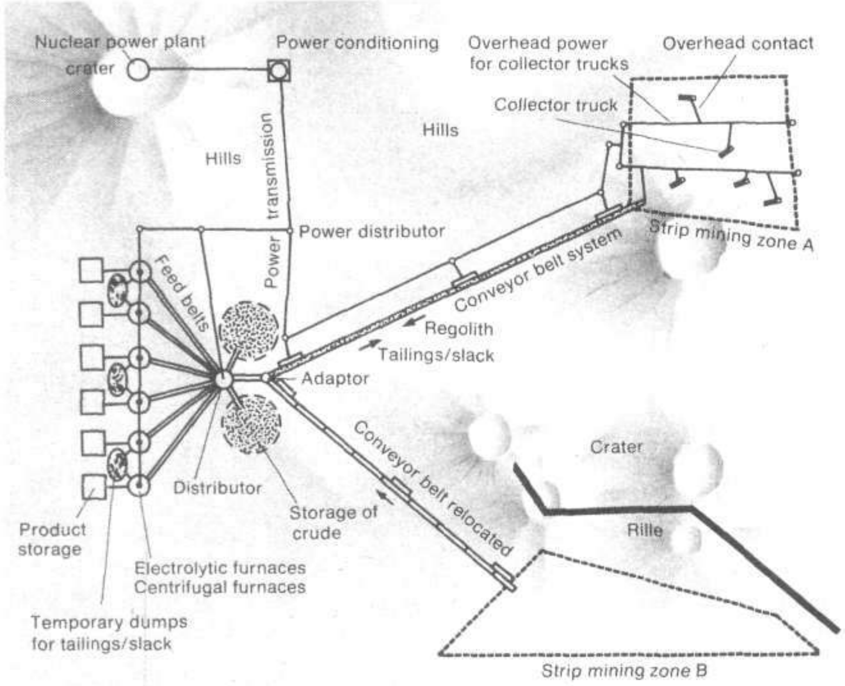
the cathode, where the release of specific metals can be controlled by means of the voltage levels applied. Oxygen, sulfur, and chlorine belong to the stronger electronegative elements; hydrogen, sodium, magnesium to the stronger electropositive elements. Aluminum, iron, and titanium are weaker electropositive elements, requiring higher voltages for deposition at the cathode.

In addition to melting lunar materials for electrolytic processes, heat can be used for fractional distillation, because of widely differing melting points (or vapor pressures) of the components in vacuo, and for thermal instead of electrolytic dissociation. Effective reduction can be achieved by passing hydrogen, CO, or compounds such as CH_4 through molten lunar material—for example, through mare basalt melt, which is rich in silicon and iron oxide. Other reducing methods include mixing finely ground, heated material with any of the above gases, or mixing any of the gases with evaporated lunar material.

The sources of heat for reduction are, in order of increasing temperature: the high-temperature reactor (HTR), with reactor cooling gas outlet temperatures of 900 to 950 degrees centigrade; nuclear-electric arcs (these are less suitable for quantity production); solar concentrator-heater ovens, for temperatures of up to several thousand degrees and low mass requirement (these are inoperative, of course, during the 354-hour long lunar night); under-

Figure 3
SEMISTATIONARY MINING-BENEFICIATION-PROCESSING/REFINING FACILITY

Stage three of lunar development: This nuclear powered electrolytic and centrifugal furnace facility is part of the Central Lunar Processing Complex. Surface mined material is sorted and fed into the furnaces. Different metals, silicon, and other outputs are removed from the furnaces to product storage as industrial feedstock for semifinished and finished products; for transport into circumlunar orbit and further processing at zero-gravity; or for export to customers in circumterrestrial orbits and on Earth.



ground atomic ovens (UAO), stoked by small fission or fusion detonations; and the plasma from a fusion reactor, once this technology is developed.

For early application and high-mass flow, day and night, the HTR and the UAO are the most effective methods, besides solar heating during the day.

Figure 3 shows a typical arrangement for a strip mining-beneficiation-refining facility. The facility uses electrolytic and thermal-centrifugal, as well as other reduction and separation furnaces. Strip-mined lunar crude is fed into the furnaces by conveyor belts that also serve to transport tailings and slack back to the strip mine zone. The entire system is powered by a pebble bed thorium HTR that breeds U-233 fuel from thorium-232, thus avoiding production of the more dangerous plutonium-239. Later, a combination of a thorium breeder HTR and molten-salt reactor (MSR) will be used, the former furnishing processing heat, electric power, and U-233 fuel excess, the latter using the excess for generating more electricity. The MSR is in some respects even more convenient to maintain than the pebble bed HTR.

The nuclear power facility will be located at some short distance in a suitable crater or canyon, whose walls will provide safe shielding.

Nuclear Pulse Technology for Underground Detonations

Since my first publication on lunar detonation mining in 1972, I have investigated a broad variety of operational modes in applying this technique (Ehricke 1972a). Only a brief overview can be presented here. The open and peaceful application of nuclear energy, including the release of nuclear detonation energy underground, is permitted by the International Treaty on Outer Space (1967). By underground detonation, surface and surface conditions are not affected. Nuclear energy is the most effective form of energy because it has the lowest entropy and mass. This applies to nuclear power plants and even more so to nuclear detonation.

In order to extract 10,000 tons (Earth tons) of O_2 annually, for example, thereby also reducing a corresponding mass of silicon, iron, aluminum, titanium, and so forth, a net energy of about 75×10^9 kilocalories per year must be invested. This corresponds to the energy contained in 15 detonation units at 5 kilotons (kt) each, at a combined weight of less than 15 tons.

Even if one considers that this mass is only 5 to 10 percent of the overall operational mass that must be imported from Earth for detonation mining, and even if the oxygen recovery factor is only 50 to 33 percent, requiring 30 to 45 five-kt or 10 to 23 ten-kt-detonations annually, the ratio of mass produced (O_2 and reduced materials) to the initial mass invested is huge (80 to 100). This output to input ratio is still very large if one accounts for all the equipment and energy needed to separate the elements contained in the reduced mass. After the basic equipment is installed and only charges have to be supplied, the output to investment ratio becomes much larger still. At the same time, the detonations are too small to interfere with physical laboratories and astronomical observatories established 1,000 to 2,000 kilometers from the Central Lunar Processing Complex.

The caverns for UAOs will be blasted in bedrock (solid mare basalt, a pre-Imbrian rock). Because of the total

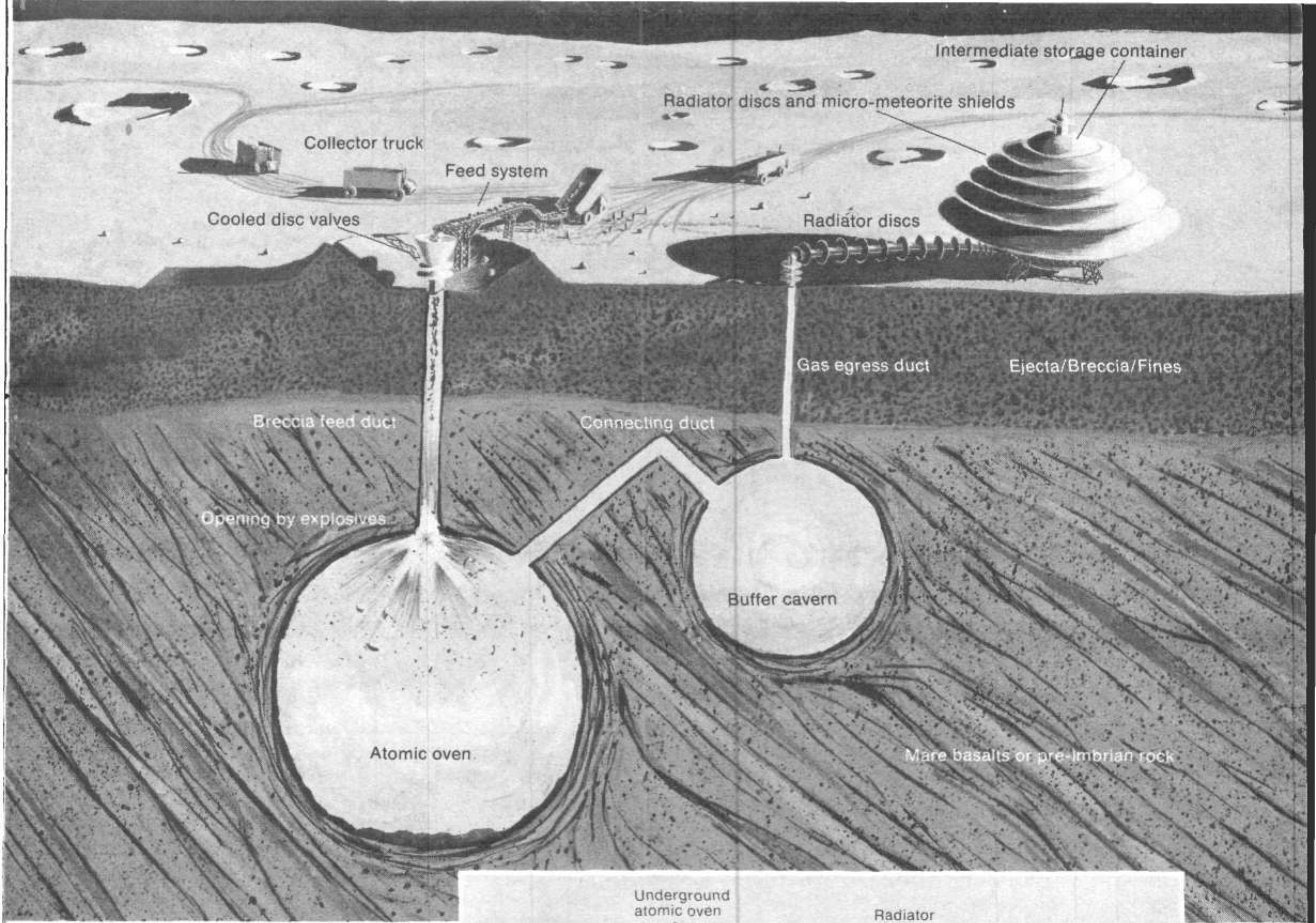


Figure 4
ATOMIC OVEN SYSTEM FOR GAS EXTRACTION AND RAW MATERIAL REDUCTION

Nuclear energy is used to extract vitally important oxygen from lunar materials and to generate man-made ores of enriched materials. Underground caverns are blasted by small nuclear detonations. The heat is contained in the desiccated, low-heat-conducting lunar rock. Lunar crude is fed into the atomic oven from the overlying loose breccia layer, either as fines and sand or as crushed breccia, to provide a maximum surface-to-mass ratio for maximum outgassing efficiency (reduction efficiency). The oven is stoked by a nuclear detonation as required. Next to it is a buffer cavern into which the very hot gas is released prior to begin fed into intermediate storage containers and on to the liquefaction complex.

Illustration by Christopher Sloan from a diagram by Krafft A. Ehricke

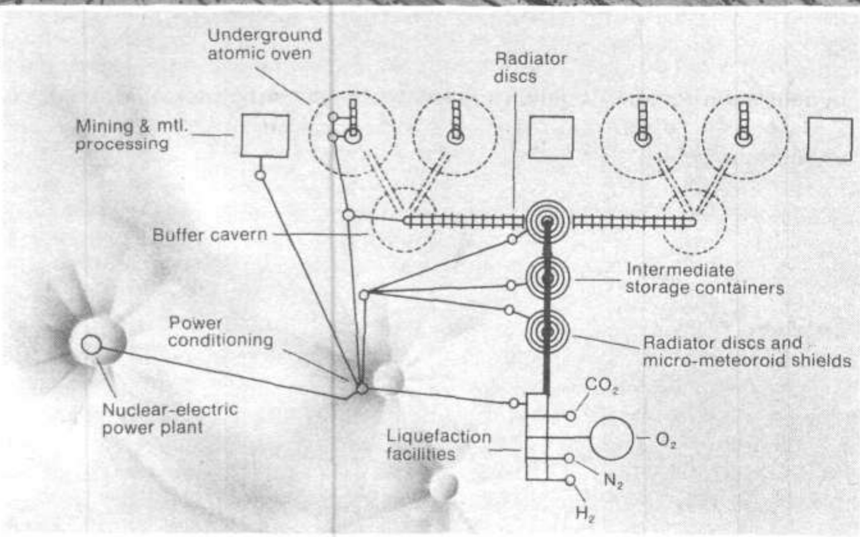


Figure 5
LUNAR GAS AND MINING COMPLEX USING UNDERGROUND ATOMIC OVENS

Shown here is an advanced UAO arrangement in the Central Lunar Processing Complex. A series of UAOs is used sequentially, alternating between hot state for gas extraction (until filled to a certain level with reduced materials) and cold state for mining the reduced material (for subsequent separation and refinement). The mined UAO is then ready for another cycle, which begins by stoking the UAO with a nuclear detonation.

dryness of the rock, there is no steam generation. This is an important advantage since on Earth, steam cracks the walls, leading in the higher gravity environment to a collapse of the cavern ceiling and, thereby to chimney formation, cooling the underground cavern relatively fast.

On the Moon, the detonations will generate caverns with highly compressed, glassy walls. They can be expected to be so water-impermeable that the cavern could be used as a water reservoir without danger that the liquid would be lost quickly by being soaked up by the noncompressed surrounding rock. The heat conductivity of the material is very poor by terrestrial standards, keeping the heat concentrated in the wall of the oven and lava pools. This means that the detonation energy is essentially dissipated productively in the processed material.

Figure 4 depicts a simple UAO system for gas extraction and raw material reduction. After blasting, the initial nuclear detonation heats up the interior lunar rock, producing an intense thermal radiation from the walls. Lunar material is then fed into the oven, preferably fines and sand for maximum surface area and hence maximum reduction efficiency. (The larger the rock, the smaller is its surface in relation to the mass; this renders the escape of oxygen more difficult, leaving a core of oxidized minerals, and lowers the efficiency of the process.) Oxygen evaporates out, and the de-oxidized elements form an enriched ore, which may subsequently be separated into its constituents.

Figure 5 shows a plan for an advanced arrangement of UAOs in a facility for gas extraction and mining of reduced materials.

It is fortuitous that the lunar crust is much poorer than Earth in elements that could be turned into undesirable radioisotopes by the neutrons released during the detonation (for example, strontium, cesium, yttrium, antinomy, and so forth). The detonation process itself releases radioisotopes if it is fission, whence fusion detonation is preferable.

Terrestrial experience with underground detonations shows that the bulk of radioactive fission material collects at the bottom in puddles of liquified rock. On the Moon, at lower gravity, the fissioned material is likely to be somewhat more widely distributed along the lower calotte walls. Much fission material has a short half-life. Only 100 days after the detonation, 63 percent of the radiating material consists of only three isotopes: strontium-90, strontium-89, cesium-144, which have half lives of 28 years, 50 days, and 284 days, respectively, where the longest radiating strontium-90 contributes about 20 percent to the overall radiation after 100 days.

As the cavern fills up with reduced material, the radioactive parts of the cavern are increasingly covered. Consequently, because of mostly short half lives and the shielding effect of coverage with reduced materials, radioactivity within the oven declines rapidly and is at a minimum when mining begins. Moreover, the so-created mine is cleared out by robots. The de-oxidized material itself is not radioactive and can readily be handled once removed from the UAO and delivered to the material processing facility. There is practically no limit to the amount of lunar materials that can be processed annually by a combination of UAOs and nuclear-electric power plants.

A Lunar Development Strategy

The four guiding principles of the lunar development strategy outlined above are designed to ensure its steady progress, early economic viability through market assurance, and supply crisis resistance. Only on this basis can lunar industrialization be developed early, effectively, and in a financially responsible manner. And only rising productivity and sustained economic growth can underwrite an ever increasing lunar population and the development of high Selenian living standards.

Market assurance guarantees that the costly lunar capital equipment and installations remain functional and productive when market demands change. Supply crisis resistance ensures that lunar personnel do not have to be returned to Earth because they cannot sustain their lunar existence without the delivery of basic inputs from Earth, or do not have the "credit worthiness" to receive loans on the basis of a recognized payback capability in a reasonable amount of time—in principle, the situation that choked off the Apollo program.

Interruptions in a steady development pace are costly and time consuming beyond the interruption proper. Therefore, crisis resistance must be kept high by keeping the ratio of up-front investments and lead times to initial productive capability to a minimum, through maximizing high, diverse, and low-cost productivity.

In addition, the ratio of investments and lead times to positive cash flow (even if this is not yet *net* positive cash flow) should be kept as small and as brief as possible. To express the principle succinctly: Maximum of value-generation capability and value-generation flexibility should be achieved with a minimum of initial expenditure and lead time. For example, the construction of a large colony for thousands of inhabitants as an initial investment before the productive and market foundations are laid, flies in the face of economic logic.

Lunar industry should be conceived of as an organism that, over the course of time, evolves to progressively more complex capabilities and generates sufficiently strong foundations for rising population and expanding cultural activities. Therefore, the nuclear central lunar industrial base and ballistic supply feeder systems from different metallogenic provinces have first priority, along with the crews required to establish them.

In accordance with the above outlined strategy, five evolutionary stages of the selenosphere (the Moon world) may be defined:

Stage one involves synoptic prospecting to further detect metallogenic or mineralogenic provinces and obtain other necessary advanced information to identify promising sites for future feeder stations. This stage will be carried out using simple landers, electrically propelled orbiters for observation and communication, and a Lunetta reflector orbiter for illuminating the perpetually shadowed places at high latitudes and the polar regions

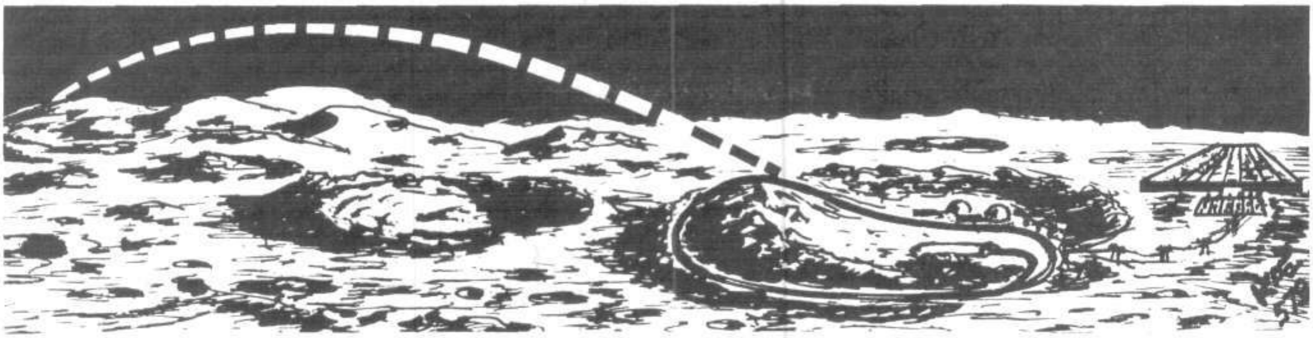


Figure 6
BALLISTIC DELIVERY OF LUNAR CRUDE TO CENTRAL PROCESSING COMPLEX
Stage four of lunar development: The establishment of feeder stations in certain metallogenic provinces permits the Central Lunar Processing Complex to draw on sites of richer than average content of industrially needed materials. Ballistic transmission is the simplest form of delivery: The lunar crude is hurled into a designated receiving crater in the vicinity of the CLPC, from which it is transported to the appropriate processing facility. The energy requirements for ballistic transmission are modest, because of low lunar gravity.

for purposes of photographing, cartographing, and possibly identifying polar ice deposits (see Figure 1).

Aside from the low probability that ice will be found, its discovery would not be likely to benefit lunar development (Ehricke 1981). Precisely its potential economic value and its rarity would make it a source of many problems. The international implications would be complex and, by holding up lunar development, almost certainly negative. Small usable findings would become a bone of contention not only between potential users for whom there would not be enough, but also between the potential users and those who would clamor to declare the region a lunar national park and prevent extraction of the ice in the first place. In consequence of these rivalries and the resulting bureaucratic paralysis, lunar development might grind to a halt or be severely handicapped.

After all, in view of the availability of lunar oxygen, only 9.1 percent of the mass of water requirements would have to be imported; and the hydrogen used first as a propellant component in ascending from the lunar surface could be made to perform a double duty. Such considerations clearly put an upper limit on the economic worthwhileness of using polar ice, whose location, should it exist, in the polar mountain wilderness in scattered deposits, possibly in layers not much thicker than hoar frost, may render its mining very costly.

The centerpiece of **stage two** is the establishment of a circumlunar space station (CLSS). Located in low circumlunar orbit (CLO), the CLSS will act as a control and operations center for more sophisticated ground systems, dispatched from Earth directly to the lunar surface, because this is less costly than first transmitting them to the CLSS. The CLSS will also function as an engineering and biological laboratory experimenting with lunar materials delivered from different parts of the Moon by automated returners. Finally, the CLSS will act as the habitat and operations center for Moon Ferry (MF) operations with at first, for cost reasons, rather limited numbers of surface missions.

Therewith, the CLSS is an important, cost-saving, and indispensable training station for the "first generation" ground personnel for stage three. The MF ground excursions from CLSS and back will deploy, calibrate, start up, and service more complex biological, industrial and other demonstration models that will be mailed to the lunar surface directly from Earth.

While existing transportation capabilities will be used to maximum extent in this no-frills lunar development approach, stage two will also have to make major strides in developing special, highly cost-effective transportation systems, particularly in research, development, testing, and engineering for the lunar slide lander, for lunar launch facilities designed to capture the exhaust steam from ascending vehicles, and for the development of a nuclear-electric geolunar freighter. (These vehicles will be discussed in the second part of this article.)

In stage two, the pace of development must quicken for economic reasons—namely, stage two is more costly than the first, exploratory stage of development (though not nearly as costly as it would be if the same functions were carried out from a lunar ground base), and it is not yet a production phase; stage three is the first production phase, in which supplies not only move from Earth to the Moon, but goods and services flow from the Moon to previously identified markets in geolunar space, and on Earth itself.

In **stage three**, a first-generation Central Lunar Processing Complex (CLPC) with a nuclear power station will be established. It will probably be located on the far western regions of Oceanus Procellarum, at or near the equator, for a variety of reasons. Among them is ready and low-cost accessibility from Earth, as well as from the CLSS, and the fact that the flat territory between 50 and 60 degrees western longitude clearly appears to be one of the places particularly suited for slide landing.

As with all the phases, the foundation for stage three will have been laid in the previous phase. In stage two, a CLSS can carry out most of the necessary preparatory work for a ground station at considerably lower cost than if such a station were established right away on the lunar surface. In addition, personnel can be trained and their medical/psychological profiles examined during periods of living in isolated conditions far from Earth, especially the profiles of people who live in "two worlds"—namely, in low circumlunar orbit and intermittently, for a few days or weeks at a time, on the lunar surface. Ground personnel will thereby be trained to run the CLPC in stage three for shift periods of at least 9 to 12 months, because as stage two crews in the CLSS they will already have become accustomed to duty cycles of 6 to 9 months or longer, and to spending weeks at a time on the lunar surface.

These crews will be intimately familiar with the biological, exploratory, engineering, and medical experiments conducted—from handling tools and equipment to construction techniques. The latter will span the gamut from cold-welding cut lunar rocks, producing lunar bricks and possibly cement with lunar sulfur as binder instead of water, to compacting lunar fines (powdery to coarse sandy material) into building blocks for lunar igloos ("ligloos"). These ligloos will have sprayed airtight inner liners and airlocks, in order to provide shirtsleeve shelters, workshops or "green houses" for planting food, built out of mostly local materials. The crews will be accustomed to work, manipulate teleoperators, and supervise robots under various conditions, day and night, to perform cold welding in the lunar high vacuum as well as laser and electron beam welding, to carry out surface mining and drilling, and to monitor/maintain a wide variety of equipment and agricultural modules.

With the crews thus trained, production runs are scheduled to begin in stage three for oxygen, silicon, aluminum, iron, glasses, and other materials; and from these raw materials on to powder metallurgy, vapor phase metallurgy, production of solar cells, computer parts, and eventually of space habitat structures, communication platform structures, antennae, service satellite parts, reflector structures, and much more.

In stage three, novel transportation arrangements are put into operation, radically lowering the costs of getting to and from the lunar surface and across cislunar space. The CLSS of stage two grows into a staging base, training second-generation selenauts, and expands into a zero-gravity factory. Stage three already aims at diversified markets.

To broaden market response capability, feeder stations are established in **stage four**, at places that were identified in stages one and two as having a greater local abundance of certain raw materials (Figure 6). These feeder stations are very simple, most of them unmanned, controlled and operated from orbit. Materials are collected in the area surrounding the feeder station and ballistically transported to receiver craters near the CLPC. At the CLPC, the expensive industrial facilities and launch complex are concentrated, so that they do not have to be duplicated at various lunar sites, with less assurance of productive operation continuing with changing market requirements than if the lunar crude in demand at the time is delivered

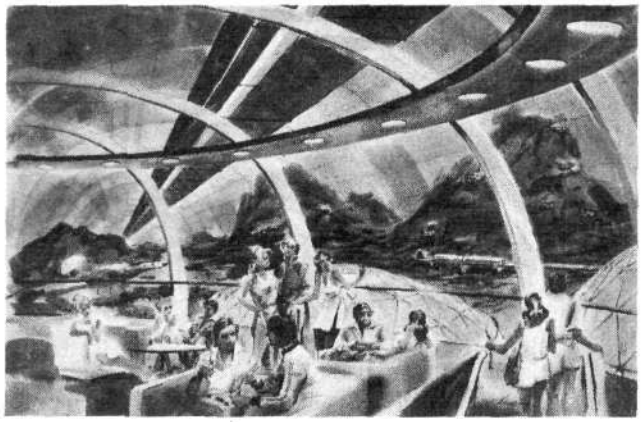


Figure 7
IN THE SUNBELT OF SELENOPOLIS
Stage five of lunar development: Coolers and conversation at the Diana Club provide the foreground for this desert scene in Selenopolis. In the background, tennis courts and the Alan B. Shepard golf course offer the old recreational activities in a new gravitational dimension. In the far background stretch crop lands for plants and fruit flourishing in the Mediterranean climate. A monorail transportation system (background, right) connects the "Sunbelt" with other climatic, industrial, and agricultural areas. Sunlight is reflected through the ceiling and spread over the "sky" by a system of mirrors.

to one fully equipped and expanding central processing complex where the necessary power sources, equipment, and human skills are concentrated.

The lunar population will begin to increase in the fourth stage, commensurate with economic growth and the prospects for further industrial expansion. With the expansion of and improvements in the civil engineering, life on the Moon will become increasingly more urbanized.

Stage five is contingent upon a strong economic foundation, resting on a powerful fusion energy base. These prerequisites will make possible the development of Selenopolis, city-state seat of lunar civilization and the lunar biosphere. Enclosures of from 500 meters to several kilometers in width, and of 500 meters and more in height will gradually expand for many kilometers across the lunar surface, and in some parts beneath it. Additional sections and branches, benefiting from the earlier experience and use of progressively more advanced lunar technologies, will be added as the lunar population grows (Figure 7).

Nodal points will serve as power, supply, and climatic control centers. They will maintain different climates—continental, dry subtropical, and semiarid to begin with—and climatic cycles, where applicable, at different phases at a time. In this way, for example, winter and summer can exist simultaneously in different sections with continental climates. Other sections will have climates that are adjusted to their special agricultural functions in order to maximize plant growth (measured as yield per unit area and number of crops per annum). This will be accomplished primarily through CO_2 enrichment of the atmosphere, temperature, humidity, and suitable irradiation cycle, all coordinated to achieve optimum combination.

After stage five, no further developmental stages need to be defined or could they be planned meaningfully. The new world is launched and grows into the future according to its own laws.

The Logic of Development

The achievements of each developmental stage can be identified as belonging to one of three main sectors: technosphere (research, technology, industry), biosphere (plant and animal life, food production, general plant growth, selenobiosphere), and sociosphere (habitats, living and working spaces, society, economy, politics, and culture).

There is an associated economic and industrial rationale for the transition from one developmental stage into the next: This logic postulates the operation of lunar base industries as the transition from stage two to stage three. The payoff of the initial investments begins in stage three, at first at a relatively modest rate. This payoff is a prerequisite for expansion on a larger scale from stage three to stage four—it is necessary for lunar profitability to assist with the larger investments of stage four and to demonstrate credit-worthiness for attracting major terrestrial investment capital.

In stage four, industrial production and services expand. Diversification grows beyond extraction and semifinished products into finished products and assemblies. Beyond this, strategic economic positions must be attained in supplying orbital and terrestrial markets, yielding a high gross lunar product that not only builds a positive balance of trade, but also builds the infrastructure and establishes the credit-worthiness for continuing expansion.

In order to accomplish the transition to stage five, it is necessary that at the end of the fourth and the beginning of the fifth stage, the balance of trade must shift significantly in favor of lunar industry, so that further expansions can be financed largely from earnings. The crucial factor here is the introduction of fusion power plants during stage four.

Construction and progressive expansion of Selenopolis will again require more massive imports from Earth. And again, it is postulated that the expansion progresses commensurate with economic growth and the ability to sustain a corresponding increase in population; the expansion is thereby financed to a high degree out of lunar capital.

With this premise, we move into the twilight zone between economics and politics. Analysis of pertinent factors—social, economic, and the onset of the social and cultural extraterrestrialization process—suggests the inevitability of this development. Thus in stage four the issue will arise as to what extent conditions in stage five will be financed and controlled by terrestrial institutional power.

As defined here, stage five is a state in which trade relations with Earth are based on rough commercial equality—on a basis of mutually complementary value generation, not with lunar civilization in a receiver position vis-à-vis Earth. This presumes a high degree of fiscal and economic self-determination and cannot help but encourage political implementation. The existence of an independent, promising seleneconomic potential will also attract terrestrial investment capital from nations, corporations, and orbiting enterprises. Therefore, much will depend on lunar political status and prospects by the end of stage four: Will it be a colony of Earth, part of the common heritage of terrestrial mankind, or an independent political entity with Selenians in control of their world? Underwritten by fusion power, the vast potential of the lunar economy renders the latter alternative possible and hence likely.

Krafft Ehricke has been involved for more than 40 years in the study and development of space technology, exploration, and utilization. During his professional career he has been involved in the development of many "firsts," including the German V-2 missile; the Atlas, the first U.S. ICBM; and the Centaur, the world's first oxygen-hydrogen *upper stage rocket, whose development he conceived and directed.*

Ehricke has done studies for NASA on many advanced concepts—from large reusable launch vehicles and space habitats to advanced propulsion systems and planetary missions. For his ideas on the inevitable integration of Earth and space environments (the extraterrestrial imperative) as a process following evolutionary laws, he received the I.B. Laskowitz Award of the New York Academy of Sciences in 1972, among others.

Ehricke is founder and president of Space Global Co. in La Jolla, Calif. The author of numerous articles, he is currently finishing two books for a German publisher, one dealing with the industrialization and settlement of the Moon, the other with the disposal of nuclear waste in space. A long-finished work, The Extraterrestrial Imperative—From Closed to Open World *awaits publication.*

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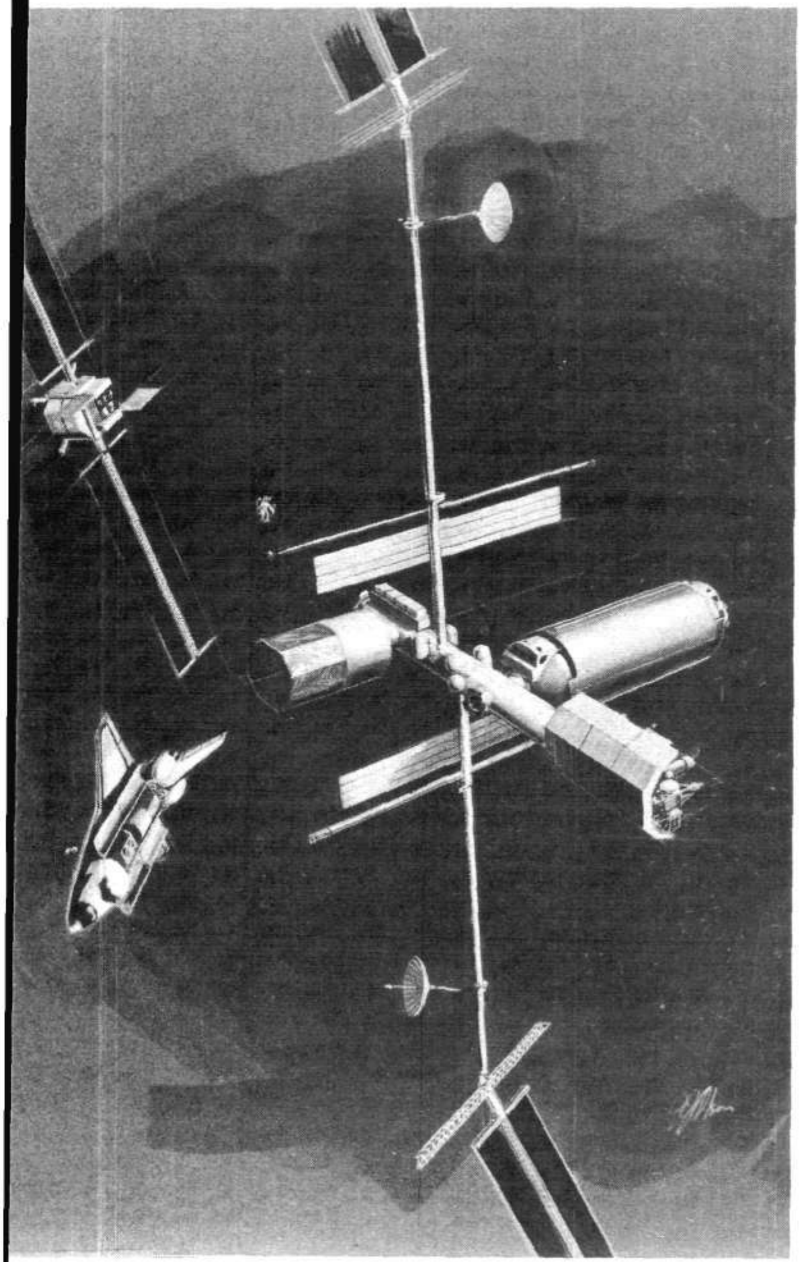
The Space Operations

A Permanent

by Gordon Woodcock



The Space Operations Center, being designed for NASA by Boeing Aerospace Company, would be a permanently manned orbiting space station to be launched into low Earth orbit by the Space Shuttle. Here is an artist's depiction of the initial stage of the SOC spaceport.

The initial station would include a living and command module, a logistics module, and a service module. It could accommodate a crew of four for up to 90 days without service from Shuttle visits. Boeing estimates that if NASA were to make a commitment now to complete the SOC design work and begin construction, this initial SOC could be in orbit by 1989.

Illustrations by John J. Olson, courtesy of Boeing Aerospace Company

THE FIRST FLIGHT of the Space Shuttle Columbia marked the fruition of eight years' work by the National Aeronautics and Space Administration (NASA) and its contractor team to bring about a revolution in space flight. More than just a remarkable new flying machine, the Shuttle is the beginning of man's using space as an operational environment, a new milieu for mankind, an extension of our existence beyond a thin layer near the surface of one planet. This revolution will take place gradually, not all at once, but NASA is already planning the next steps.

Space flight of any sort is itself a revolution. For millennia, men and women gazed at the sky and wondered about the objects beyond the Earth; they yearned to someday visit those places, to explore and perhaps to live. In the latter half of the 20th century, this age-old dream has begun to be realized.

Although man has visited only one other world, the modern technologies of automation and communication have allowed millions to visit many others vicariously, through our robot spacecraft. And as we have developed space technology, we have found many ways to derive practical benefits to society from the use of this new environment. It is these practical benefits that the Shuttle is primarily designed to exploit.

The revolution brought about by the Shuttle, in fact, is vital to continued progress. The heritage of earlier space vehicles is the artillery rocket, a device for hurling a payload to a precise point in space. As our use of space grew and matured, the high cost and very limited operational capability of expendable artillery rockets has become more and more of a burden.

The Space Shuttle introduces the reusability and operational flexibility of aircraft technology, bringing about the first true space transportation system. Many of the missions now planned for the Shuttle will use it as a space platform, for assembly, observation, or experiment missions. On these missions the Space Shuttle will conduct operations not heretofore practical.

The logical next step in this evolution is the creation of a permanent manned operational presence in space to expand our capability for space operations beyond what is practical with the Shuttle. To fulfill this need, the Space Operations Center (SOC) concept was devised by the NASA Johnson Space Center.

Placed in low Earth orbit by the Shuttle, the SOC would begin to extend our operational base beyond the surface of the Earth, opening the way to continued growth in

Center

Station in Space

space mission size, duration, and complexity, without demanding continued growth in the scale of the supporting launch systems. The SOC would be serviced and supplied by the Space Shuttle.

A Beachhead in Earth Orbit

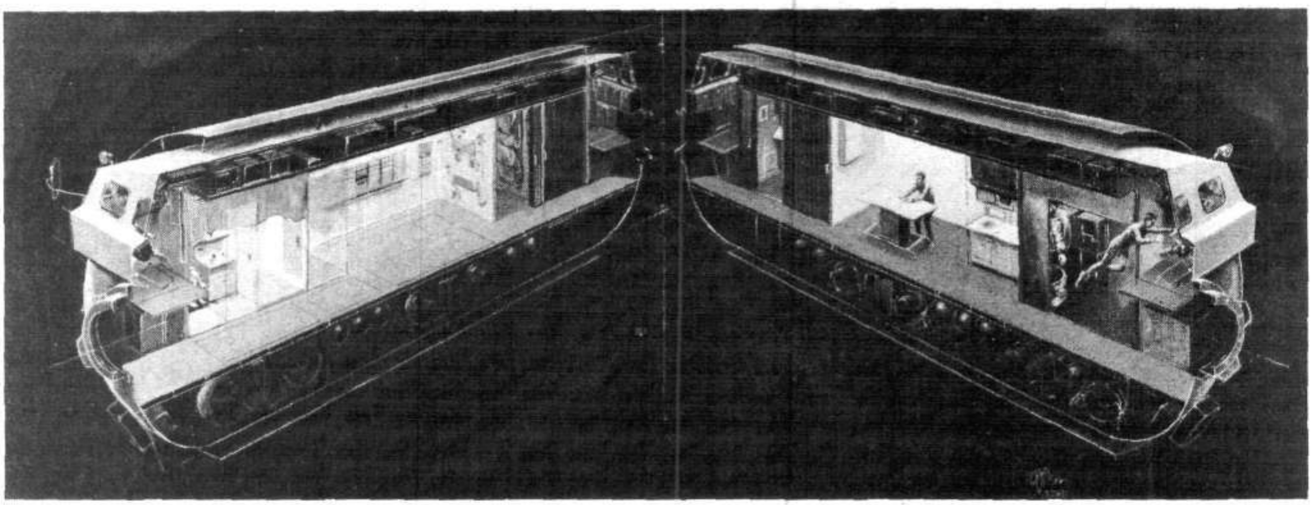
Just as the Shuttle is a departure from its predecessor launch systems, the Space Operations Center concept is a departure from earlier manned orbital facility concepts in its mission and design approach. Earlier space station studies emphasized science and applications missions; the stations designed by these studies were mainly individual research laboratories, such as Skylab. The SOC is intended as a facility to support and conduct space operations such as assembly, checkout of satellites, servicing, and launch from space of many kinds of spacecraft.

The objectives set out by NASA for the SOC include providing operational support in low Earth orbit for increasingly complex future space missions and systems; minimizing the need for each Shuttle orbiter to spend extended periods of time in space, thus maximizing the launch availability of each orbiter in the Shuttle fleet; and accommodating space missions that require long periods in low Earth orbit with frequent or continuous crew involvement. NASA intends to establish these operational capabilities before 1990.

In order to meet these objectives, NASA determined that an SOC should have the capability for assembly and checkout of large orbiting systems in space before they are deployed for their work in space and the ability to assemble, launch, recover, and service these space vehicles while in operation. The SOC will also supervise free-flying satellites that have no human crew but co-orbit with the SOC and reduce dependence on Earth of permanently manned operations in space for their control and supply.

The Space Operations Center flight crew will serve as an extension of the eyes and hands of the people on the ground, accomplishing tasks that would be impossible or impractical to carry out without a crew in orbit. Their intelligence allows them to work either autonomously or cooperatively with ground crews to solve problems. They provide feedback to ground crews in ordinary spoken English (not computer language) and can react quickly and rationally to unexpected or emergency situations.

With an SOC, NASA will be able to conduct space missions with fewer Shuttle flights. Satellite servicing, for



Artist's drawing of the interior of a Space Operations Center, including the inside of one of two living modules. The command and control center is at the left. This center is capable of controlling the entire SOC, which will be independent of ground control. At the center is the lavatory, shower, dressing room, and exercise and recreation area for one crew member along with private sleeping quarters, which include a desk, lights, and a small television. You can see a second sleeping quarter compartment with the door closed for privacy. On the right is the other half of the observation deck, sleeping quarters for the other two crew members, and the galley area.

example, can be done without scheduling a Shuttle flight for each servicing need. Equipment can be based at the SOC rather than carried to and from orbit for each use. The SOC crew will service satellites of all kinds—weather, communications, scientific, and others—in orbit near the SOC as well as spacecraft in higher Earth orbit.

The nearby satellites will be accessed either by maneuvering the satellite or SOC to close proximity so the SOC crane can berth the satellite for service, or by having the crew use backpack maneuvering units, or a teleoperator maneuvering unit that functions like a tug between the SOC and the satellite. Access to satellites in high orbits will require a manned or automated OTV, Orbit Transfer Vehicle, which would be propelled to meet the satellite and return it to the SOC.

Typical servicing functions include changing film or other media equipment in scientific instruments, replacing or adjusting instruments, replenishing consumable supplies in the satellite, and repairing or maintaining equipment of satellite subsystems. Initial servicing will rely mainly on replacing modules. As experience develops, it is anticipated that smaller modules that do not present a hazard to the crew may be taken inside the SOC from the satellite for repair and checkout in a shirtsleeve atmosphere at an electronic service bench in the SOC itself.

This capability will extend the useful life of many satellites that are now abandoned when they malfunction or when they simply need parts that are worn out replaced.

Vehicle Assembly in Space

Present-day spacecraft use elaborate mechanisms for deployment of appendages, antennas, and instruments on spacecraft after they are in orbit. As spacecraft grow in size, the assistance of flight crews in deploying and installing equipment or appendages will become important. Such use of manned abilities on Shuttle flights will begin in the near future.

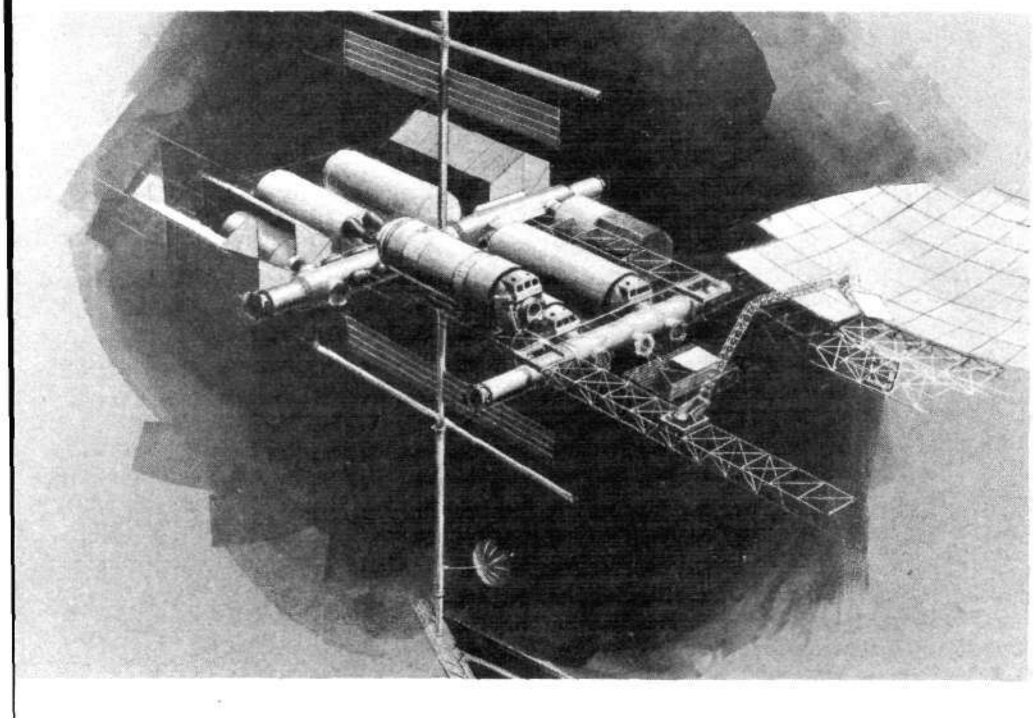
But the growth in complexity of these tasks will begin to place a premium on crew time in orbit, and the benefits of a permanent facility will increase. Checkout activities will increase in duration, and large multibeam antennas, for example, may require final calibration and adjustment in orbit—a task that could require days to weeks.

The flight crews on the SOC will conduct these activities in a manner generally similar to satellite servicing. Equipment installation and deployment or assembly operations will be performed as Extra-Vehicular Activity by crew members (going outside the SOC in space suits) or remotely through manipulators, depending on the task content and complexity.

Many payloads anticipated during the SOC period of operation will be large enough in size or mass to require that they be brought to orbit in stages on separate Shuttle flights. In these instances, SOC crews will conduct vehicle assembly operations, mating the upper propulsion stage to the payload, at the SOC.

As spacecraft and space operations technology advance, true space construction operations may begin. Large antennas and other artifacts may be *fabricated* in orbit from detail parts brought from Earth, and interconnecting structures may be fabricated in space using space beam fabrication techniques already demonstrated in the laboratory. Platforms to hold many satellites together and provide modular servicing as well as other space structures and large spacecraft will eventually be fabricated, assembled, checked-out, and launched *in space*.

Although the major function of the SOC is not scientific (it is a servicing center for all space operations), the interior of the SOC offers considerable space to accommodate scientific laboratory experiments that use the zero



In this drawing of an advanced SOC, facilities have been added not only to service and repair satellites, but also to store and operate a manned Orbital Transfer Vehicle (OTV), which could take payloads from the SOC in low Earth orbit to a higher orbit in space. The pair of habitat modules could now accommodate an increased crew of eight. Each module will have redundant living and control systems so that each can function safely independently.

The advanced space center would include hangars for OTVs and other spacecraft (much like airplane repair hangars on Earth), warehouses for food and water, solar panels to provide electric power for the station, and service modules and supplies. In addition, multiple propellant tanks could be stored for future missions.

gravity environment. For these activities, crew involvement would be similar to that experienced on the Skylab missions where some experiments were done directly by scientists and some were maintained by the regular crew.

The facilities of the SOC, and the frequent Shuttle visits for spacecraft and other deliveries, will enable experimenters themselves to visit the SOC to carry out their research.

SOC Design

The SOC is modular in design. Each element can be launched by the Shuttle, and the elements can be assembled using only the Shuttle and its Remote Manipulator System, which will be flight-tested on the second flight of the Shuttle orbiter Columbia. The size, shape, and mass of the SOC elements have been selected to maintain this compatibility with the Shuttle system.

The modular design also lends itself to the establishment of an evolutionary program. The initial SOC uses three modules, each self-contained, and the operational configuration adds three more along with mission service equipment. The SOC design provides a high degree of redundancy and safety. It would simply be too expensive to leave a Shuttle at the SOC at all times for emergency return to Earth, and it would be contrary to the objective of enhancing Shuttle transportation effectiveness, as well.

Consequently, the design philosophy is more that of a submarine, with on-board capability to survive emergencies and restore the vehicle to normal operation. As a result, the operational configuration includes five isolatable pressure containers plus a resupply module with a high degree of modular interchangeability between the modules.

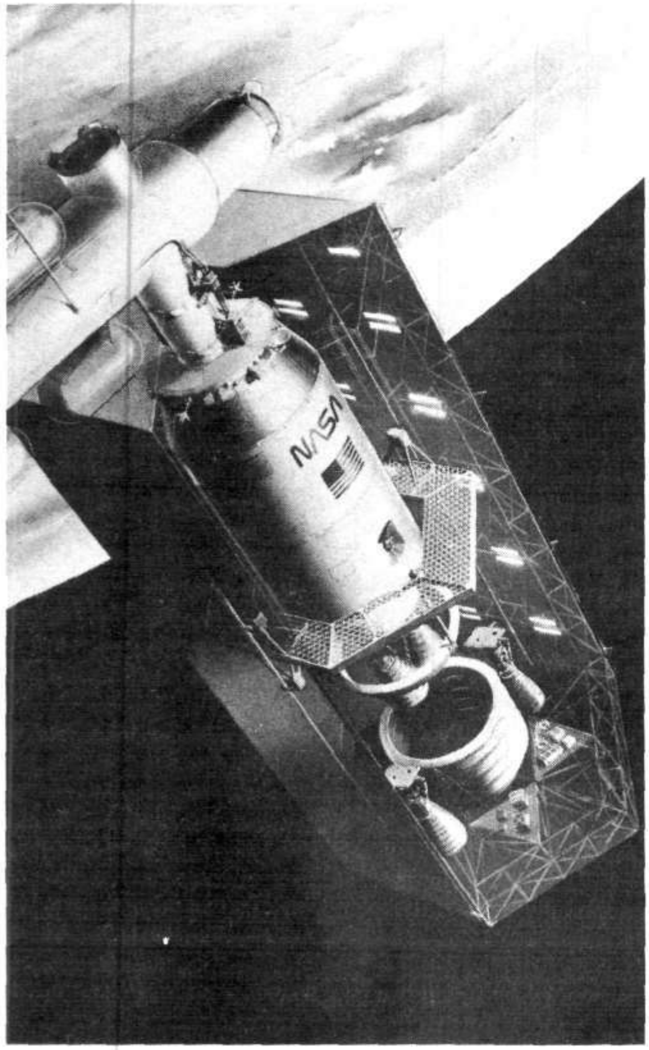
Any one modular container can support the entire crew until a Shuttle rescue can be carried out. The on-board maintenance and repair provisions include spares, tools, and equipment such that the normal outcome of an emergency condition would be repair and return to normal operations.

The design configuration of the SOC provides for continued growth beyond the operational phase, including the possibility of adding science and applications experiment modules, propellant tank farms for propulsion systems into high Earth orbit, and extended construction facilities.

The Space Shuttle system allows a manned crew to remain in space only for two weeks. The Space Operations Center will extend man's stay in space for 90 days at the beginning and longer periods of time in the future.

In the long run, the most important benefit may be the simple fact that new capabilities always engender new ideas and technologies, benefits we cannot even imagine today, in the formative stages of these new capabilities.

Gordon Woodcock is the manager of the large Space Systems study group for Boeing Aerospace Company. An aeronautical engineer and a nuclear engineer, he has worked in the aerospace field for 25 years, including the Apollo program, missile systems, and the Shuttle's preliminary design phase.

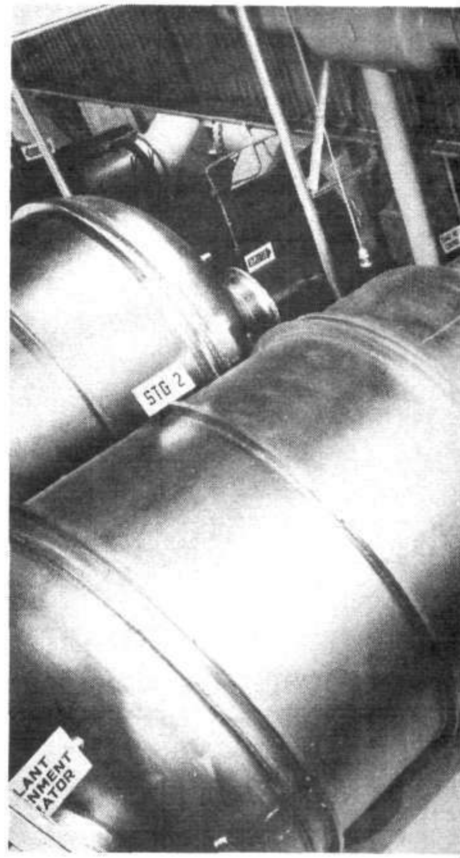


An Orbital Transfer Vehicle being serviced in the hangar of the SOC.

The SOC will orbit the Earth just a couple hundred miles above the Earth's atmosphere. Many scientific and commercial satellites, however, need to be 22,300 miles above the Earth in geosynchronous orbit. At this height the satellites remain above the same spot on the Earth because its orbit rate is the same as the Earth's rate of rotation. All communications satellites, for example, are in this region.

In order to deliver to geosynchronous orbit the new satellites the Space Shuttle brings up, the SOC will need a fleet of Orbital Transfer Vehicles (OTV), reusable liquid-fueled spacecraft that are manned or unmanned. The OTV would be a very flexible vehicle, which would allow the schedules of the Shuttle and SOC to be independent for satellite delivery and insertion into final orbit. The SOC could store the satellites as they are delivered from the Shuttle and then make its own schedule for deployment into space by its fleet of OTVs. The SOC would do a final check of the satellite and make repairs if necessary.

Isotope separation has been the key to the development of the most advanced frontiers of 20th-century science and technology, in particular nuclear fission and fusion. If declassified and fully developed with the aid of plasma bombardment, it will cheapen energy production and revolutionize materials science.



Advanced Isotope Separation

Nuclear Chemistry for the 21st Century

by Charles B. Stevens

EDITOR'S NOTE

This is the first of two articles reporting on a Fusion Energy Foundation project for making the generation and separation of advanced isotopes the centerpiece of a revived Project Plowshare, the peaceful nuclear explosives program of the 1960s. Part 1 reviews the history and current status of isotope separation. The second part will describe the FEF's proposed new approach to isotope separation that is based on using Riemannian isentropic shock waves in plasmas, and will discuss proposed applications of this approach such as the gamma-ray laser.

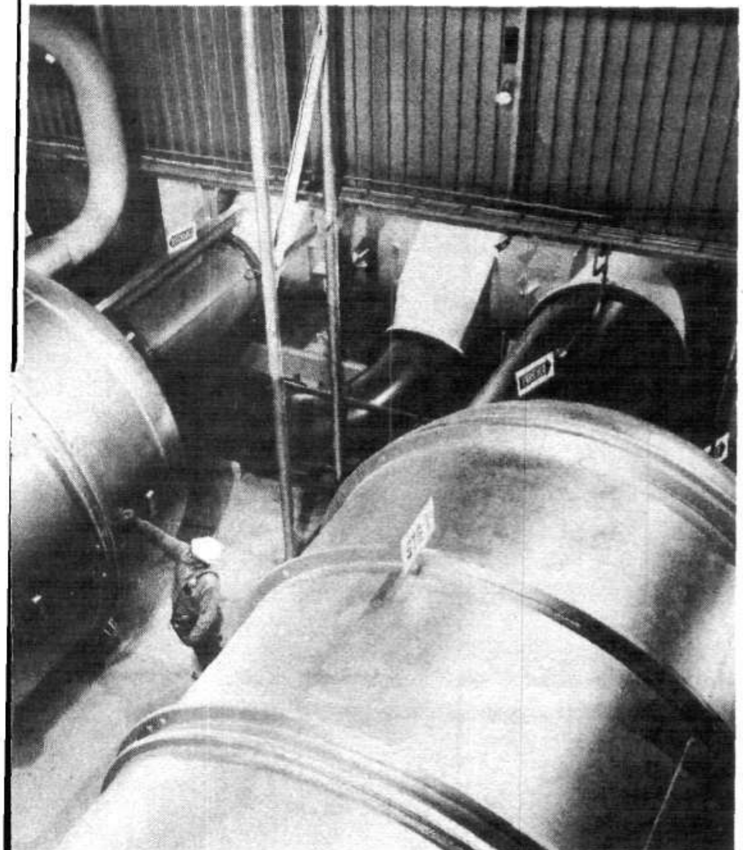
* * *

THE LEAST KNOWN yet potentially most beneficial technology associated with the atomic bomb is advanced isotope separation—the technology of transforming the basic elements into their most useful forms. Were the United States to declassify and fully develop advanced isotope separation, its applications could make nuclear fusion and fission energy production vastly more efficient. Just to take three examples, advanced isotope separation could (1) cheapen by many billions of dollars the enrichment process of crude uranium to produce the fissionable isotope uranium-235, thus assuring an inexpensive supply of fuel for nuclear fission plants; (2) isolate hazardous radioactive isotopes from nuclear waste, turning them into usable isotopes and vastly reducing the amount of material that has to be disposed of as waste; and (3) create new materials and metal alloys that would be impervious to the fast neutrons produced in fission and fusion, thus allowing for the development of more advanced energy-dense reactor designs.

Most important, declassifying isotope separation research will open up new ways of examining the laws of the universe, revolutionizing the concept of the periodic table of the elements.

Like inertial confinement fusion research, isotope separation work has suffered under the chill of classification. Isotope separation techniques were developed during the war by the Manhattan Project in order to construct the first uranium nuclear fission bombs, separating the fissionable isotope U-235 from the naturally occurring and much more prevalent nonfissionable U-238. (Fissionable U-235 makes up only 0.7 percent of the uranium found in nature; the rest is U-238.)

Since the Manhattan Project, no commercial development of isotope separation has been permitted, and the theoretical work has been stymied. In the early 1960s, in fact, out of concern for isotope separation technology in particular, the Atomic Energy Commission came up with the infamous "born secret" interpretation of the 1954 Atomic Energy Act. According to this interpretation, all classified information concerning nuclear technology and especially isotope separation is "born secret." Even if a scientist were to independently derive the basis for an existing technology or a new one, his thoughts on this subject would be "born secret" and would have to be



Oak Ridge Gaseous Diffusion Plant

For 35 years the United States has used the gaseous diffusion (barrier diffusion) method of isotope separation to produce enriched uranium for nuclear fuel, supplying 90 U.S. reactors and 79 reactors in 16 countries. Shown here are the diffuser vessels that contain the barrier material.

immediately submitted to the supervision of government classification policy.

Mendeleev, Elements, and Isotopes

In the latter part of the 19th century, the Russian scientist Mendeleev approached the problem of putting chemistry and chemical engineering on a scientific basis by developing a means of categorizing the chemical elements. Mendeleev began by making what was then a radical assumption: that the chemical elements constitute a totality whose individual members are fundamentally interrelated. In this way he was able to arrange the then known chemical elements according to their various physical and chemical properties. This led to a complex geometric ordering of the elements, which proceeded in linear terms according to atomic weight—the number of neutrons and protons found in the nucleus of the particular chemical element. This is familiar to all chemistry students as the periodic table.

There were many holes in Mendeleev's original chart and it was not until the pioneering nuclear physics work of the Curies in the early 20th century that some of these missing elements became known. In the 1930s, using concentrations of these newly discovered radioactive elements, scientists developed energetic atomic beams with which they bombarded atoms of the heavier elements, generating many chemical elements of lesser atomic weight. They were also able to create entirely new types of elements that had the same chemical and physical properties as the old elements but were highly radioactive. These new types of elements were called isotopes, from the Greek word meaning "in the same place." Isotopes of a chemical element generally have the same chemical and physical properties but differ in their nuclear structure in terms of the number of neutrons present in the nucleus. Thus U-235, which is fissionable, has 143 neutrons, while the nonfissionable U-238 has 146 neutrons.

The Manhattan Project tried a variety of approaches to isotope separation for generating the amount and quality of fissionable U-235 needed for constructing the atomic bomb. *Barrier diffusion* was the chief method used, and this is still the main technology used today for the production of nuclear fuel for light water reactors. A crude, inefficient, and costly method of separation, barrier diffusion is based on the small difference in mass of molecules that consist of differing isotopes. Uranium hexafluoride gas is pumped through thousands of miles of permeable material that acts as a sieve, since the lighter uranium hexafluoride containing U-235 penetrates farther into the barrier material. When extracted from the barrier material, the gas then has an increased content of U-235. This gas, now enriched in U-235, is then reintroduced into the barrier sieve to obtain still higher concentrations of U-235.

This diffusion system uses enormous amounts of energy. When it was constructed during World War II, the Oak Ridge (Tenn.) Barrier Diffusion Plant was the largest industrial structure ever built, and it consumed more electricity than the total produced by the Soviet Union in the year 1939! Today, four power plants are devoted solely to producing power for the plant.

After the war, more advanced systems were developed both in the United States and abroad. The *gaseous centrifuge* and *nozzle* approaches, for example, made use of the hydrodynamic flow characteristics of uranium hexafluoride gas. These alternative approaches are 10 to 20 times more efficient than barrier diffusion in terms of energy costs, but they involve larger capital expenditures.

In the late 1960s when laser fusion was developed, the potential for using lasers for isotope separation began to be explored. (Two laser processes are shown here schematically in Figures 1 and 2.) In the late 1970s, a fourth approach began to emerge: the use of magnetic plasmas for separating isotopes, a technique whose potential had been known since the Manhattan Project (Figure 3).

These more advanced systems have significant advantages over the more conventional methods, including the newer centrifuge and nozzle approaches. The laser separation scheme, for example, is so efficient that depleted uranium—that is, uranium from which most of the desired U-235 isotope has already been removed in a barrier diffusion separation plant—could be used as the feedstock

ISOTOPE SEPARATION METHODS: KEY COSTS AND ECONOMIC FACTORS

	Oak Ridge Gaseous Diffusion Plant (Full Power)	New GD Plant (Current Tech.)	Current Planned Gaseous Centrifuge Enrichment Plant (GCEP)			1990s Advanced GC System	Advanced Isotope Separation			
			Bldg. 1-2	Bldg. 3-8	Full GCEP 1-8		Atomic Vapor Laser		Molecular Laser	Plasma Process
			Set III	Set IV	Set IV	Set VI	JNAI	LLL		
Reference Size (in millions of annual rate of SWU capacity)		9.3	2.2	9.9	13.2	8.8	10.0	8.61	8.75	9.35
Power KWH/SWU	2,360	2,475	135	95	95	48	54	65	77	221
Investment										
Unit Cap: $/annual rate SWU	—	505	1,425	281	498	280	63	77	107	100
Power Plant: $/annual rate SWU	—	434	24	17	17	8	10	12	13	39
Total: $/annual rate SWU		939	1,449	298	515	288	73	89	120	139
Annual Cost										
Power Cost: $/SWU[1]	83	87	5	3	3	2	2	2	3	8
Oper. Cost: $/SWU	5	9	16	14	14	10	9	6	8	7
Cap. Cost: $/SWU[2]	—	82	232	46	81	46	10	13	17	16
Total: $/SWU	88	178	253	63	98	58	21	21	28	31

1. At 35 mills/KW hr.
2. At 10 years and 10%, 16.28% per annum on total investment. Since the various projects require different building space, auxiliaries, etc., an attempt was made to pick reasonably comparable construction periods.

Compared here are the output, investment costs, and annual costs of current and projected methods of isotope separation. The table is taken from the Department of Energy's "Report of the Energy Research Advisory Study Group on Advanced Isotope Separation," dated Nov. 1980.

The measurements are all in mid-1980 constant dollars (no escalation), and all the methods are evaluated on a comparable basis. The basic unit of measurement shown is the SWU, or separative work unit, a standard measure of enrichment process work in kilograms. An SWU measures the extent to which a mixture of isotopes of a chemical element has been enriched with one of the isotopes. Usually the original mixture of isotopes is that which is found in nature. Starting with natural uranium, which has a 0.7 percent content of U-235 and a 99.3 percent content of U-238, it requires 275 SWUs to obtain 1 kilogram of uranium that has a 98 percent content of U-235. Fuel for fission reactors usually has about a 4 percent content of U-235.

input. In addition to consuming up to 10 times less electricity, both the laser and plasma separation systems do not have the scaling problems inherent in the more conventional approaches; the advanced systems can operate efficiently with much smaller-size plants.

The Current Status of Advanced Isotope Separation

Just as the U.S. nuclear industry has been drastically curtailed over the past decade, so isotope separation production and research has been cut back. The U.S. barrier diffusion plants are currently operating at less than one third of their capacity. Nevertheless, the three plants involved consume upwards of 2,400 million watts of electricity per year in producing fuel for nuclear fission power plants.

The Advanced Isotope Separation research program of the U.S. Department of Energy had a budget authority of $80 million in fiscal 1981 and $85.7 million in 1982. But in order to fully develop the new, cheaper laser and plasma separation systems into full-scale production plants by the

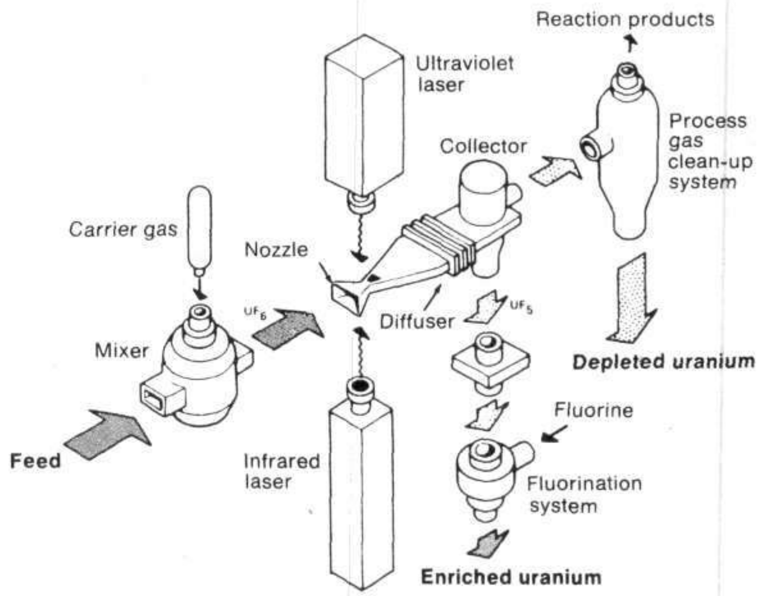


Figure 1
MOLECULAR LASER ISOTOPE SEPARATION PROCESS
In this photochemical laser process under development at the Los Alamos National Scientific Laboratory in New Mexico, uranium hexafluoride is selectively energized and dissociated by infrared and ultraviolet laser radiation. Enriched uranium is then obtained as solid uranium pentafluoride, which is separated out from the gaseous uranium hexafluoride.

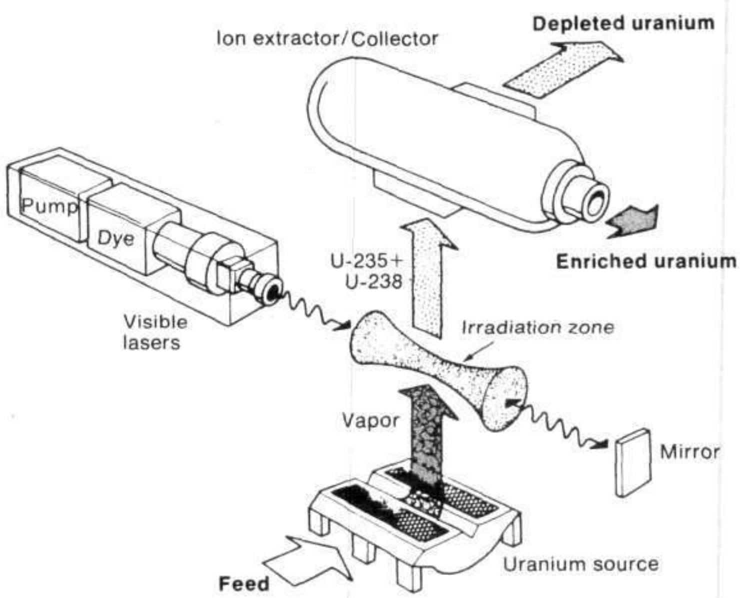


Figure 2
ATOMIC VAPOR LASER ISOTOPE SEPARATION PROCESS
This atomic process being developed at Lawrence Livermore National Laboratory takes advantage of the small isotopic differences in the electronic spectra of uranium atoms. The process requires the controlled vaporization of uranium atoms followed by excitation and ionization of U-235 (ionization is indicated by the plus sign) using tunable lasers in the visible regions of the spectrum. The plasma of enriched uranium can then be physically removed from the uranium vapor by electromagnetic methods. Collection of the uranium can take place as a liquid condensate or as a solid.

latter part of the 1980s, scientists in the program estimate that research funding should be on the order of $150 million for 1982, and greatly expanded after that.

Molecular laser isotope separation. In the molecular laser separation approach being developed at Los Alamos National Scientific Laboratory, uranium is introduced into a mixer where it is converted to uranium hexafluoride, UF_6 (Figure 1). The UF_6 is then passed through a nozzle in which it is irradiated with infrared and ultraviolet wavelength laser beams. Because of the slight differences in the molecular electron energy structures (electron spectra) of the differing isotopes of uranium in the UF_6 gas, the coherent laser beams interact with individual UF_6 molecules in quite different manners. The molecules of the lighter U-235 isotope absorb the laser energy, and in the process lose one of their six fluorides to become uranium pentafluoride. For the most part, the heavier molecules of U-238 in the UF_6 gas are unaffected by the laser light.

Since uranium pentafluoride becomes a solid under conditions that leave uranium hexafluoride as a gas, the

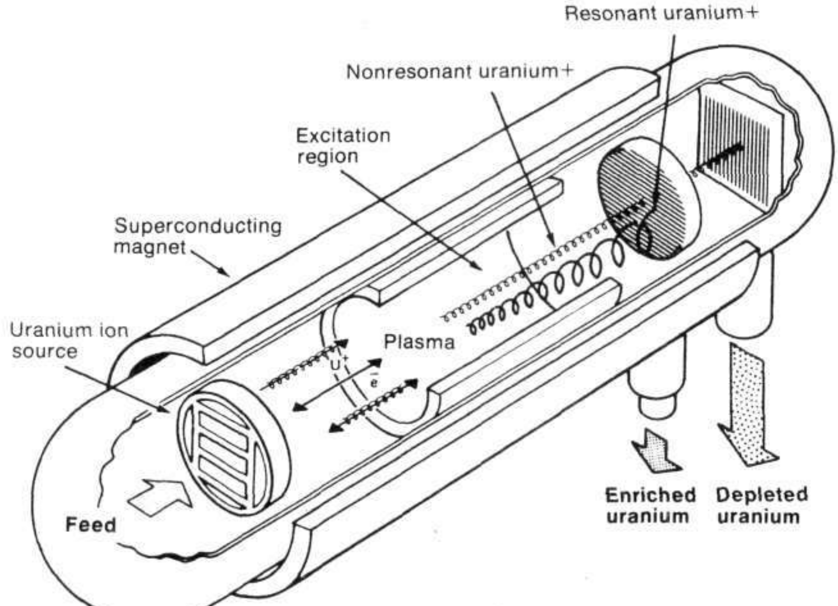


Figure 3
PLASMA ISOTOPE SEPARATION PROCESS
The plasma process, under development by TRW, Inc., is based on the principle of ion cyclotron resonance. The method involves generating a stable plasma in a magnetic field, then energizing the ions of different isotopic species that have different ion cyclotron frequencies. Radio frequency energy additions result in an increase of the cyclotron orbit of the desired component. This difference in orbits is used to geometrically separate the nonresonant depleted uranium from the resonant enriched uranium. Processing occurs in a cylindrical vacuum chamber, which is located inside the field of a large cryogenically cooled superconducting magnet.

two are easily separated in a diffuser, and the uranium that has been enriched in the lighter U-235 isotope is collected.

Atomic vapor laser isotope separation. The atomic vapor laser separation process, under development at Lawrence Livermore National Laboratory, takes advantage of small differences in the energy levels of the electrons in uranium atoms of differing isotopes. As shown in Figure 2, uranium is passed through a feeder in which it is vaporized. This uranium vapor then flows through an irradiation zone where it is irradiated by a number of laser beams at differing wavelengths. The laser wavelengths are arranged so that for the most part only the U-235 absorbs the laser light efficiently. This leads to the ionization of the U-235 atoms (designated by a plus sign in the figure).

The uranium vapor, now containing U-235 ions, then passes through an ion extractor-collector. This part of the system utilizes magnetic fields to separate the ionized U-235 atoms from the rest of the uranium vapor that contains both U-235 and U-238. The electrically charged U-235 ions interact with the magnetic field and move at a right angle to the flow of the neutral atoms, which do not interact.

Plasma isotope separation. The plasma separation process is under development by TRW, Inc., and appears to be much more versatile than laser separation because it does not depend on the particular electronic structure of the isotopes that are to be separated. Using lasers for separation, for example, requires a precise wavelength that varies depending on the particular isotope being separated. The plasma approach, however, can be readily applied to almost all isotopes.

Although a latecomer to the advanced isotope separation program, the plasma approach has made significant progress, and a quarter-scale industrial module is currently being completed at TRW's Redondo Beach facility. The approach was developed in the mid-1970s by scientists working in the magnetic fusion research effort, who took advantage of the tremendous progress in plasma theory and technology in the magnetic fusion program to rapidly perfect a workable plasma separation scheme.

In the plasma process, shown in Figure 3, uranium is ionized at one end of a plasma vacuum chamber. A superconducting magnet surrounding this chamber produces a strong magnetic field, which is directed along the long axis of the cylindrically shaped vacuum chamber. The uranium ions, as is the case in all magnetized plasmas, interact with the magnetic field such that they are trapped into spiral trajectories along the magnetic field lines. The rate at which the ion circles the magnetic field line along which it is trapped is called the cyclotron frequency of the ion. The size (or what is called the radius) of this circular aspect of the spiraling motion of the ion and the cyclotron frequency are determined by the energy (the velocity) and the mass of the trapped ion.

Plasma ions in general interact with electromagnetic waves, but they are particularly resonant with waves whose frequency is the same as the ion cyclotron frequency. Now, since differing isotopes have different masses, electromagnetic wave energy can be selectively deposited by tuning the wave energy to the cyclotron frequency of the isotopic ions in question. This is accomplished with radio waves in the excitation region of the vacuum chamber.

The U-235 ions absorb the radio waves tuned to their cyclotron frequency, and as a result are energized into much larger spiral orbits. Then a venetian-blind type of obstruction permits the U-238, with its smaller spiral orbits to pass through, blocking out the excited U-235 ions. The enriched uranium is then collected from the venetian blinds.

Advanced Applications

The conventional methods of separating the isotopes generated in the fuel of nuclear reactors are both costly and dangerous, because the multistage processing systems, such as barrier diffusion, incur significant losses to the environment of radioactive materials. Advanced isotope separation, in particular the plasma separation process, provides a potentially completely safe method for separating the radioactive isotopes from the ordinary chemical isotopes in the nuclear waste of fission reactors; that is, no hazardous material would be released to the environment.

The vast majority of what constitutes so-called nuclear waste is actually very valuable heavy metal and gas isotopes—in fact, a major reserve of such elements. Once cleansed of radioactive isotopes, this material would find immediate application in existing and new industrial processes. After dilution, even most of the highly radioactive isotopes could be used in remote power supplies, biological and medical diagnostics, and luminescent materials. For example, krypton 87, a relatively biologically harmless radioactive isotope, because of its chemical inertness and the low energy level of its atomic radiation, could be used as a replacement for radioactive tritium, which is the luminescent currently used to light up dials and displays on many electronic control systems in aircraft and ships.

As for the minute quantity of highly radioactive material remaining in nuclear waste, this could be transmuted into harmless isotopes using underground H-bomb detonations—a new role for Project Plowshare that would revolutionize the problem of long-term waste burial.

A second major application for advanced isotope separation is the isotopic tailoring of materials, removing one or more of the naturally prevailing isotopes, to make these materials impervious to the intense barrage of neutrons and radiation inside a nuclear fission or fusion reactor. This opens up entirely new possibilities for the design of advanced fusion and fission reactors. For example, materials such as aluminum could be used for fuel element cladding in fission reactors; new chemical molecules could be used for the fuel itself, such as uranium nitrides; and the energy-reactor characteristics of existing fuel elements and their cladding could be greatly improved.

By expanding the variety of materials that can withstand a nuclear environment, the physical operating parameters of reactors can be greatly extended. And in fusion systems, the improvement possible in the lifetime of the first wall of the reactor could essentially exclude induced radioactivity from the system altogether.

Most significant, advanced isotope separation coupled to advanced fission and fusion reactors could open up the prospects for developing new mass industries based on the generation of isotopes that do not occur in great quantities in nature.

The DOE's Assessment

In the early 1970s, Exxon and AVCO Research Co. invested in a joint venture in a company called JNAI to develop laser isotope separation. By 1976, JNAI was prepared to begin construction of a pilot plant for testing this new system, but the Carter administration intervened and would not give Exxon the necessary government permit. President Carter was quoted as saying "As long as I am in the White House, laser isotope separation plants will never be built in the United States."

The Carter administration also prevented the circulation of information about advanced isotope separation technology applications. For example, a joint study carried out by Lawrence Livermore National Laboratory in California and the Hanford Nuclear Reservation in Washington of using isotope separation to dispose of nuclear fission wastes was suppressed and not circulated even to scientists who had top security clearance.

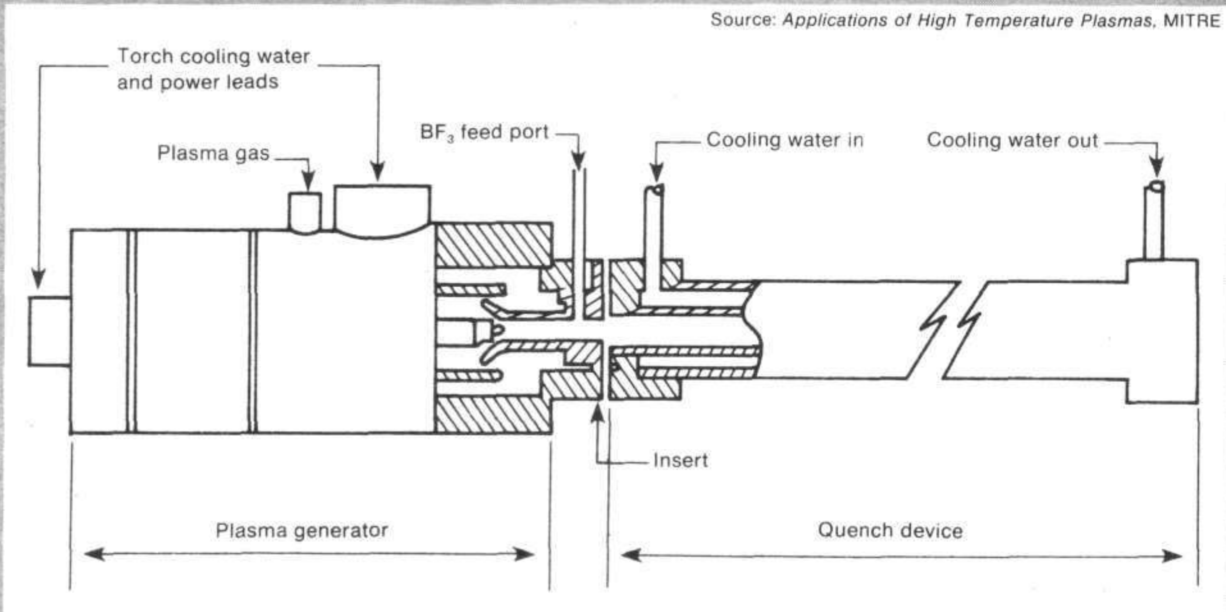
Despite this attitude, the Department of Energy's Energy Research Advisory Board Study Group on Advanced Isotope Separation published a very favorable assessment of the status of isotope separation technology in 1980. Their findings are summarized in the accompanying table (page 38), which compares the Oak Ridge Gaseous Diffusion Plant, an improved gaseous diffusion plant, various stages of developing the Gaseous Centrifuge Enrichment Plant, and the Advanced Gaseous Centrifuge system planned for the 1990s. The last four columns of the table show the projections for advanced isotope separation using the four newer methods under development.

As can be seen, both the plasma separation and laser isotope processes are many times cheaper than either the barrier or centrifuge technologies. Plasma separation, for example, costs a total annually of $31 (in 1980 dollars) per unit of material produced, compared to $178 in the new gas diffusion technology. The units of measurement are in kilowatt-hours of electricity and separative work units (SWU), the standard measure of enrichment process work in kilograms.

Since the November 1980 publication of this DOE review, Exxon's JNAI plant, which was working on atomic vapor laser separation, has ceased to exist. Work on the plasma separation process at TRW continues, as does the research at the two national laboratories, but the security wraps that have generally served to impede this work in the past are still in force. Scientific sources report that the TRW plasma separation process is currently planned to be applied to military isotope separation within four years.

Will the United States develop advanced isotope separation? The question is basically the same as that of whether the nation will develop any frontier technologies and advanced scientific research.

Charles B. Stevens is director of fusion engineering for the Fusion Energy Foundation.



The Fusion Torch

Unlocking the Earth's Vast Resources

by Dr. John Schoonover

THE CURRENT DEBATE in Washington over U.S. dependence on foreign sources of strategic minerals is premised on a fundamental misconception—that these resources are scarce, in quantity and geographically. In fact, there are vast quantities of even the so-called strategic minerals waiting to be tapped in the United States and throughout the world.

In just 1 cubic mile of ordinary rock there are 1.8 to 2.3 million tons of zirconium, compared with a U.S. annual production of 500,000 tons; 1.3 to 1.6 million tons of vanadium, compared with 3,585 tons; 1.1 to 1.4 million tons of zinc versus 260,000 tons; and 1.7 to 2.1 million tons of chromium, where the United States currently produces none.

These amounts of strategic minerals exist in their elemental form in ordinary rock anywhere in the world. The key to unlocking them is the development of the fusion torch, a technology with as revolutionary implications for opening up new mineral resources as the realization of controlled thermonuclear fusion power will have for solving the so-called energy crisis.

More than a decade ago, two prominent fusion researchers, Bernard J. Eastlund and William C. Gough, proposed an application of fusion energy to materials processing that would take advantage of the extremely high temperatures attained in the plasmas generated by fusion reactors.[1] The plasma, an ionized gas, can be brought to a temperature of 50 million or even 100 million degrees, at which temperature no material is immune to manipulation at its atomic level.

With this capability at hand, it would be possible to reduce common dirt, if that were necessary, to its elemental constituents and extract the desired metals. Valuable materials could be retrieved from garbage in a cheap and economical way. Specialized types of radiation, from the full electromagnetic radiation spectrum, could be produced to enhance existing chemical processes and to create new ones that today exist only in the fertile imaginations of some chemists. The atoms of a material could themselves be separated according to their isotopic differences, a type of materials engineering still in its infancy, which has arisen from the development of nuclear power.

◀ *A feasibility study for producing elemental boron out of boron halides using a high temperature plasma was done for Union Carbide by G. E. Biggerstaff et al. in the 1960s. The plasma gas (usually argon) is injected into the rear of the arc chamber; it flows past the tungsten cathode and through the water-cooled copper insert, which also serves as the anode. The arc is initiated by first establishing a high-voltage, high-frequency discharge in the arc chamber. This initiates the high-current DC discharge.*

(The full implications of this promising technology are discussed in an accompanying article, p. 36).

The prospect opened up by the fusion torch of creating resources out of seemingly nothing debunks the underlying premise of conservation and population control advocates—the idea that resources are finite and are fast running out. In fact, the greatest resource man has—and the only invariant one throughout human history—is his infinite creative capacity to solve the problems that continually arise as a by-product of the Earth's evolution. To advocate a reduction or even stagnation in the rate of global population growth, as do the U.S. government's *Global 2000 Report* and associated documents, is to advocate a form of resource destruction that the human species could not long survive.

Nature has never provided mankind with a bountiful supply of any raw materials. It has always been essential for man to use his creative intellect to discover ways to use the inanimate junk of the natural environment to further the development of the human species. Each such discovery has determined the extent of a *man-made* base for a mix of productive processes.

Energy Density

The critical parameter in determining how man can alter nature to his ends is the density of energy that he can bring to bear in the production process. In primitive societies, before the invention of smelting, there were no ores at all. The energy that could be applied to stone was only that which the human hand could apply by striking or rubbing the stone to fashion some primitive tool.

Once mankind mastered the use of charcoal fires, zinc and copper could be smelted together to change the rock into bronze. This process required a 10-fold increase in energy density. The use of fire for smelting had created a new resource.

Ten thousand years later, after the invention of an even more intense form of energy, electricity, it became possible to increase the energy intensity of the process of purifying zinc by electrolytic methods, and zinc became an even cheaper and more useful resource. And the increase in energy intensity made it possible to process lower grade zinc ores.

The fusion torch will increase by another factor of 10,000 the energy intensity we can apply to natural resources. This is 10 million times more energy than our first toolmaking ancestors used.

The extremely high energy density of the fusion torch makes very low grade deposits economically usable. In fact, the fusion torch will make any rock minable. We can get some idea of the implications of this by examining the mineral content of an average cubic mile of dirt and rock. If we could remove the metals from that cubic mile, we could extract nearly 200 times the annual U.S. production of aluminum, 8 times the iron produced in a year, two thirds of the copper, more than 100 times the tin, and 6 times the zinc. A cubic mile of rock is the equivalent of between 7 and 10 times annual world coal production, a large amount of material to handle and process, but one that is within technical feasibility. With these amounts of minerals available, if we develop the technology to extract them, talk of a resource crisis is sheer folly.

The Fusion Torch

In conventional methods of producing energy, heat is generated either by the combustion of fossil fuels or by splitting uranium atoms in a nuclear reactor. The fusion reaction, in transforming isotopes of hydrogen into helium at temperatures of tens of millions of degrees, produces not only heat for generating electricity by conventional or advanced conversion methods, but also magnetic radiation, charged particles, and neutral particles at high energies.

These unique by-products of the fusion process can be used to reduce metal ores, process chemicals, and carry out bulk materials separation. And unlike the fusion energy produced in the Sun, controlled fusion plants on Earth will be "tuned" to produce more or less of the various particle and radiation by-products, depending on what is required.

A fusion torch is created by transferring a plasma from the fusion reactor where it is created, through a connecting region that isolates it from the plasma source, to an interaction region. Once there, the high temperature plasma is ready for torch applications. Any solid or liquid material—scooped-up portions of the Earth's crust, oxidized ores already mined, or even urban waste—can be fed into the interaction region.

The high thermal conductivity and large energy flux of the fusion torch plasma produce a shock vaporization (propagation of shock waves) that ionizes the material. Lower temperature plasmas created by shock tubes or electric arcs cannot produce the shock waves that propagate in this ultrahigh temperature plasma. Furthermore, when lower temperature plasmas come into contact with solid materials, the plasma itself is cooled.

Once material is ionized in the fusion torch and broken down into its constituent elements, a separation technique must be used to recover the desired materials. A number of such techniques have been proposed, and some have been tested: Among these is electromagnetic separation, a technique that uses electric and magnetic fields to guide and control the electrons and ions in the plasma.

Quenching, or quick cooling of the plasma, is a promising technique that will produce the simplest molecules and prevent different atoms from recombining. This method would prevent iron and oxygen from recombining in the reduction of ferrous oxide. Quenching can be accomplished by injecting a cooler gas into the plasma, expanding the plasma, or by causing it to flow over a cooled surface.

If the temperature and density of the plasma are held constant under conditions favorable for the recombination of a desired type of material, the material can be selectively accumulated from the process.

Other methods of separation, including charge exchange, plasma centrifuges, plasma accelerators, and curved magnetic fields, have also been investigated. Centrifuges and curved magnetic fields seem to hold out the greatest promise for using fusion torch technology for large-scale isotope separation.

Revolutionizing Materials Processing

Gough and Eastlund estimated that by the year 2000, an all-electric city of 10 million people would need an electrical capacity of about 140 gigawatts (GW). If 10 GW were used to drive a fusion torch, municipal waste alone could generate 27,000 tons of recycled materials. Low grade ore bodies that are not economical to exploit by conventional methods will become attractive and eventually, with commercial fusion power widely available, whole sections of the Earth's crust could be processed to extract the important raw materials. However, such applications of the fusion process are just the beginning of the capabilities it will open up for materials processing.

To date, industrial society has used almost exclusively the infrared part of the radiation spectrum—mostly heat—in materials processing, with the use of ultraviolet (UV) radiation (in water purification, for example) still relatively exotic. However, the ultrahigh temperatures and flexibility of the plasma reaction can make available high intensity energy from every part of the full spectrum of electromagnetic radiation—ultraviolet light, radio waves, microwaves, X-rays, gamma rays, and the rest of a continuum that reaches from a frequency (the rate at which the wave oscillates) of zero to infinity.

Different forms of radiation will interact with matter in a characteristic manner related to their frequencies. Microwaves are useful for heating bulk matter and for radar, for example. Some kinds of electromagnetic radiation, especially that in the frequency range above visible light, are particularly suited for altering the states of atoms in molecules. By choosing the right frequency or range of frequencies, chemical reactions can be triggered when the radiation falls on a working fluid.

Chemical reactions triggered in this way have two principal advantages: First, the energy pumped into the working fluid is tailored to the requirements for the reaction, rather than being a simple bulk heating process; consequently, less energy is used. Second, the product is purer because by-product reactions that result from bulk heating can be largely eliminated.

The plasma produced in a fusion reaction can be "tuned" to emit a desired kind of radiation by modifying the plasma's magnetic field and composition (through the introduction of impurities). For example, by injecting trace amounts of impurities, possibly aluminum, into selected materials, the radiation field of the plasma could be "tuned" to produce high levels of ultraviolet (UV) radiation. The UV radiation can then be transmitted from the plasma through a window to the solution to be processed.

UV radiation is used commercially now for sterilizing high cost food stuffs like milk, but once it could be produced more cheaply, it could be used in the desalination of water, the conversion to electricity using fuel cells, and for many kinds of plasma chemistry.

UV photons could be used for the photodissociation of water into hydrogen and oxygen. It has been estimated that hydrogen production using a water vapor cell with UV radiation could be produced at prices comparable to proposed nuclear-based processes, and at less than current cost of electrolysis. This process is physically identical to the continual UV dissociation of water that takes place in the upper atmosphere as a result of incoming sunlight.

The Plasma Torch—A Stepping Stone

The fusion torch and plasma torch, a similar process with a lower temperature, have been researched by several private firms. Bethlehem Steel and Westinghouse have developed plasma technologies for reducing iron ore to iron and for producing both vanadium and chromium steel alloys. These processes have been shown to be economically feasible but are not yet commercially available. On the other hand, East Germany has developed a plasma torch process to produce steel from scrap metal. This process is in commercial use in both East Germany and the Soviet Union. In all these processes, the use of the very high plasma temperatures allows the process to be more efficient energetically than the conventional low temperature processes that are generally used.

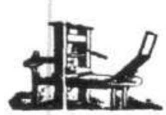
These plasma torch processing technologies are a stepping stone to the much higher energy densities of the fusion torch. The plasma torch has the advantage that it could be developed on a short time scale, even before energy-producing fusion reactors are built.

However, while the main line of research on controlled thermonuclear fusion is being slowed down by budget constraints, work on developing the promising technology spinoff of the fusion torch has never gotten off the ground. The initial work of Gough and Eastlund was never followed through on by the Atomic Energy Commission or, subsequently, by the Department of Energy. The failure to mount a government program—one of the economy measures of the 1970s—will have the effect of creating resource shortages and high prices where there could be affordable abundance.

Dr. John Schoonover is director of nuclear physics at the Fusion Energy Foundation.

Note

1. B. J. Eastlund and W. C. Gough, "The Fusion Torch: Energy, Wastes, and the Fusion Torch," Division of Research, U.S. Atomic Energy Commission, April 1971.



Exploring Our Uncharted Horizons

Geochemical Mapping for Gas and Oil

by William Engdahl

The Overthrust Belt of the Rocky Mountains, stretching from Canada down through northern Mexico, may well contain oil and gas reserves greater than the entirety of all U.S. consumption to date. Although these reserves are difficult to locate using conventional seismic methods, they can be economically mapped and exploited using exploration geochemistry, a direct detection technology that reduces the randomness of costly "wildcat exploration."

This is even better news than it seems, for some geologists maintain that as much as 80 percent of the world's untapped hydrocarbons may lie in stratigraphic and subtle traps that elude seismic geology's indirect indicators, but can be accurately detected by exploration geochemistry.

The application of geochemical analysis to petroleum exploration goes back to the observance of surface seepage of hydrocarbons near Titusville, Pa., more than 100 years ago, the event that marked the beginning of the world petroleum industry. Indeed, many of the world's first major shallow oil fields were located by observance of so-called macroseepage.

But as an exploration tool to aid in the mapping of the remaining oil and gas producing regions of the world, exploration geochemistry has enjoyed only a limited recognition.

The Politics of Exploration

Geochemical exploration and a second, complementary method of direct detection, electromagnetic mapping utilizing the telluric currents over deposits,[1] have been all but eclipsed by seismic geophysics since the latter method became hegemonic in the late 1920s and 1930s.

Every major oil company in the world has utilized geochemical exploration methods to assist its geophysical mapping; however, most use it upside-down, employing the far more economical geochemical survey only after an initial, very costly linear seismic survey or other type of geophysical mapping.

To date, Gulf Oil is the only major exploration company that has publicly acknowledged that it is carrying out major work using advanced geochemical methods on its exploration vessel, the *Hollis Hedberg*, and elsewhere. And although not discussed widely, exploration in the vast offshore areas of the Norwegian North Sea is known to make use of geochemical methods prior to seismic.

Courtesy of Horvitz Research Laboratories

Exploration geochemistry analyzes soil samples for traces of hydrocarbons, indicating oil or gas deposits below. Above, new advances in carbon mass spectrometry enable a technician to distinguish the CO_2 produced from methane in soil samples from ordinary CO_2.

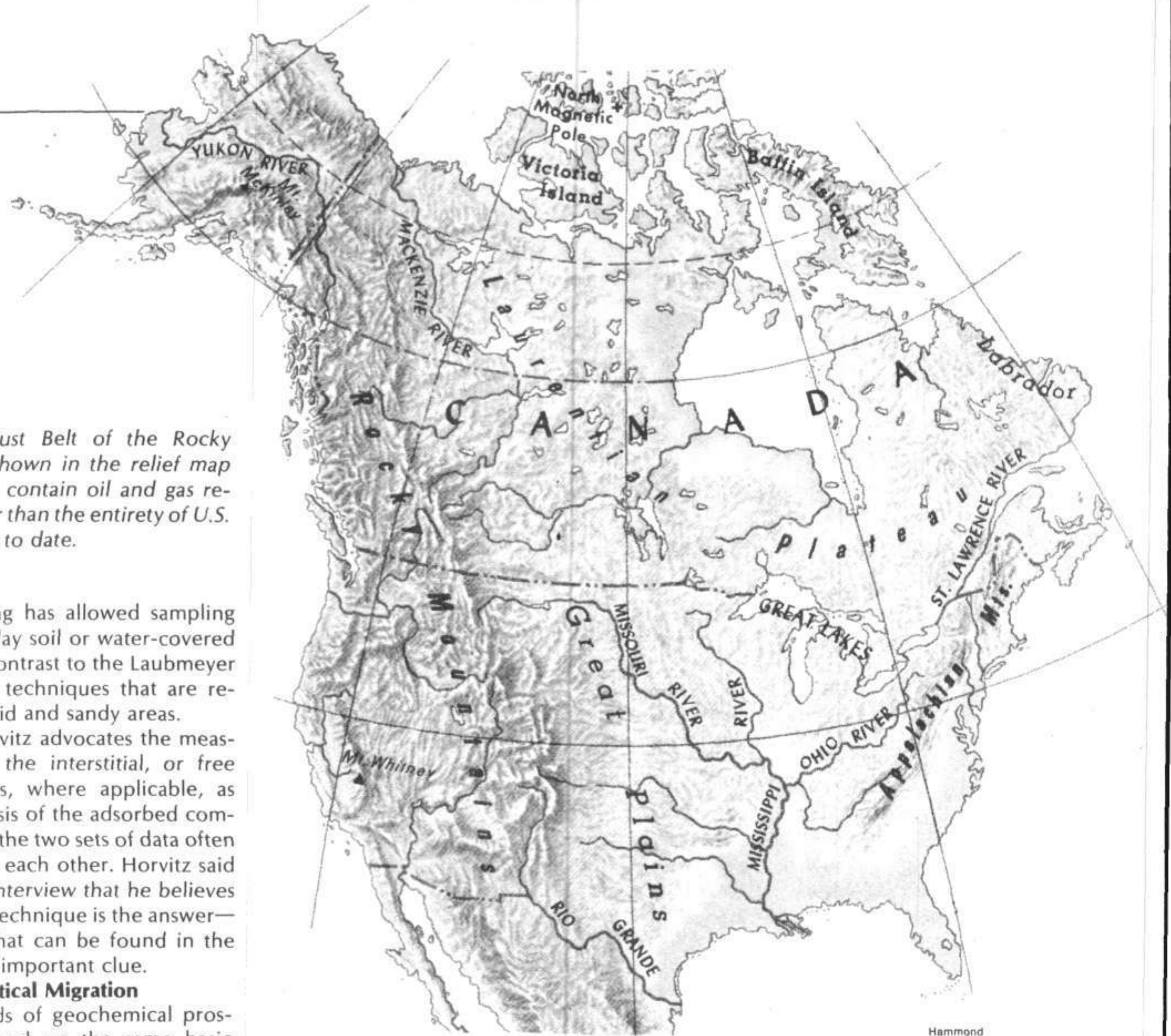
Used in tandem with structural mapping methods, geochemical techniques have clearly established their ability to narrow the costly search for hydrocarbons in large areas such as the Outer Continental Shelf off the United States. The use of geochemical survey sampling over an area of that size, onshore or offshore, can then be used to "high grade" the zone with the most promise, eliminating the dry, or nonproductive, zones before seismic work or even more costly wildcat drilling is ventured into.

The Evolution of Geochemistry

Modern exploration geochemistry is generally dated from the early work of the German chemist Dr. Gunter Laubmeyer, a noted representative of the prewar German tradition in chemistry. Laubmeyer's discovery that near-surface soil air samples collected over known gas fields contain more methane than does soil air over barren areas gave birth to geochemical prospecting for petroleum. A Russian team under the guidance of V.A. Sokolov made substantial improvements in Laubmeyer's sampling method by 1935.

The first to apply these methods in the United States was the late E.E. Rosaire, who together with Leo Horvitz, a young chemist from the University of Chicago, began the work in 1936 that essentially established the modern science of petroleum exploration geochemistry.

Rosaire and Horvitz made a substantial advance over Laubmeyer's early work. They determined that soil samples themselves, when measured with the proper laboratory analytical techniques, were found to contain larger quantities of adsorbed hydrocarbons than the soil air.



The Overthrust Belt of the Rocky Mountains, shown in the relief map at right, may contain oil and gas reserves greater than the entirety of U.S. consumption to date.

This finding has allowed sampling in areas of clay soil or water-covered regions, in contrast to the Laubmeyer and Russian techniques that are restricted to arid and sandy areas.

Today Horvitz advocates the measurement of the interstitial, or free hydrocarbons, where applicable, as well as analysis of the adsorbed components, for the two sets of data often complement each other. Horvitz said in a recent interview that he believes that no one technique is the answer—everything that can be found in the soil is a very important clue.

Vertical Migration

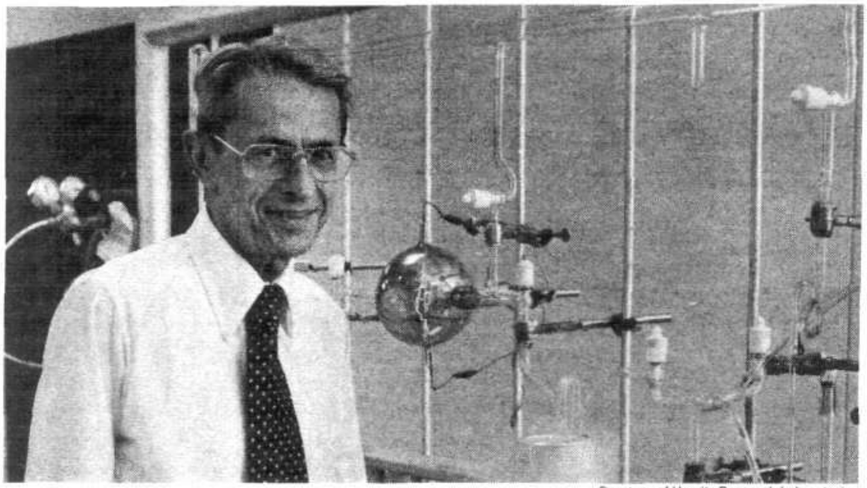
All methods of geochemical prospecting depend on the same basic fact of physical chemistry—that hydrocarbons move from subsurface oil or gas deposits in measurable amounts to the near surface, within 6 to 12 feet of the ground or water level. This vertical migration, or microseepage as it is called, has been greeted with staunch disbelief since the early work of Rosaire and Horvitz. Petroleum geologists trained to look for certain horizontal migration of petroleum found the idea of measurable amounts of hydrocarbons escaping thousands of feet through "impervious" strata to the near-surface almost impossible. This attitude, together with willful decisions by certain exploration companies, whose crude reserves in areas such as the Persian Gulf appear so immense as to discourage interest in new exploration techniques, have until now kept the science of exploration geochemistry in the closet.

Unfortunately, it had to be the political uncertainties of the post-1973 world that refocused attention on the validity of geochemical techniques. On the positive side, there has been the continuing work of pioneers in the field like Dr. Leo Horvitz, who has done more in 45 years of active scientific effort to establish the principles of the science of exploration geochemistry than any other single person.

Although the exact principles behind the vertical migration of hydrocarbons are still subject to differing interpretation, it has been firmly established that such migration does in fact occur above substantial hydrocarbon deposits.

Experimental work carried out by Horvitz has definitively refuted a contention that vegetation in the form of grass or roots could also yield measurable amounts of soil hydrocarbons.[2] However, since the abundant light hydrocarbons, or methane, in natural gas can also result from bacterial action on organic matter, Horvitz also measures concentrations of ethane and heavier hydrocarbons, which can come only from petroleum sources.

Cross-gridding of the methane concentration patterns with those for ethane and the heavier hydrocarbons



Courtesy of Horvitz Research Laboratories

Dr. Leo Horvitz, one of the pioneers of exploration geochemistry, stands near a vacuum-combustion apparatus used to purify methane and convert it to carbon dioxide needed for measuring carbon isotope ratios.

provides an extremely strong indication of significant oil or gas presence below.

The Halo Effect

In analyzing his earliest samples, Horvitz first identified what is referred to as the "halo" effect: surface hydrocarbons in a pattern of generally higher concentrations surrounding a productive structure, rather than a high anomalous range of values in the center.

The most plausible theory to explain the phenomenon that he and Horvitz had repeatedly observed was published by Rosaire in 1938. Rosaire and Horvitz hypothesized that the hydrocarbon gases are forced upward in dissolved form under the substantial temperature and pressure surrounding underground deposits, creating the characteristic halo effect. Recall that even at room temperature hydrocarbons can permeate glass, metals, ceramics, and other relatively impermeable strata. The work of Horvitz and Rosaire established that hydrocarbons do indeed pass in measurable amounts to the surface above underlying hydrocarbon deposits without significant lateral offset.

This migration phenomenon is at the center of the science of exploration geochemistry. And it fully correlates with the physics of the electromagnetic telluric currents over hydrocarbon deposits documented by R. G. Talbert.[3]

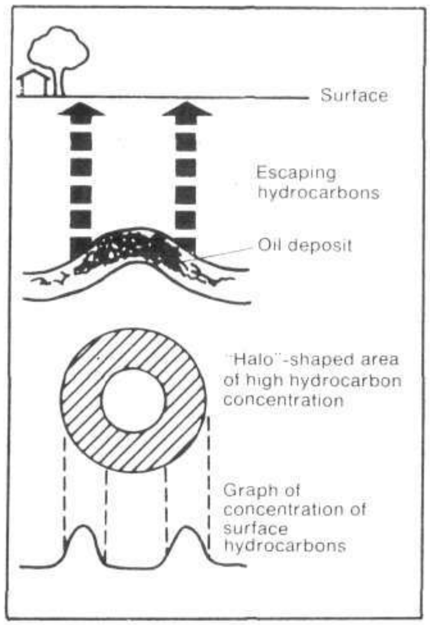
The accuracy of the hypothesis was put on a firm scientific foundation through work initiated by Horvitz in the early 1970s using carbon isotope studies. It is now possible to determine through isotope data whether different hydrocarbon samples come from the same or different sources by knowing their C-13 to C-12 ratios. This work has been made feasible through recent advances in mass spectrometry.

Over the past 40 or so years, Horvitz Research Laboratories based in Houston has analyzed well over 50,000 soil samples, both onshore and offshore, from throughout the world. Drilling results have confirmed the value of geochemical analysis as a major exploration tool. For example, a survey conducted prior to the 1974 offshore Louisiana lease sale produced an outstanding halo-type anomaly. Subsequent exploratory drilling led to the discovery well of the Cognac Field. Of 11 additional exploratory wells drilled, 75 percent were in locations within the anomaly mapped with geochemical methods.

Fluorescence

A recent development in exploration geochemistry has been the discovery that the same type of fluorescence spectra produced by crude oil are produced by soils and sediments in the near-surface over oil fields. When crude oils are excited using an ultraviolet source with a wavelength of 265 nanometers, an emission peak of the sample is emitted at 320 and 365 nm.

This interesting new exploration technique was first developed by Donald B. Purvis, an exploration geochemist from Gretna, La. Purvis began his research in 1964 at the biochemistry department of Mississippi State University. He recounts that his work with the phenomenon of fluorescence began casually when he worked during the summer as a mud logger on an oil rig. There he observed the common procedure of holding well cuttings under a hand-held ultraviolet light to detect fluorescence, indicating the presence of crude oil in the sample.

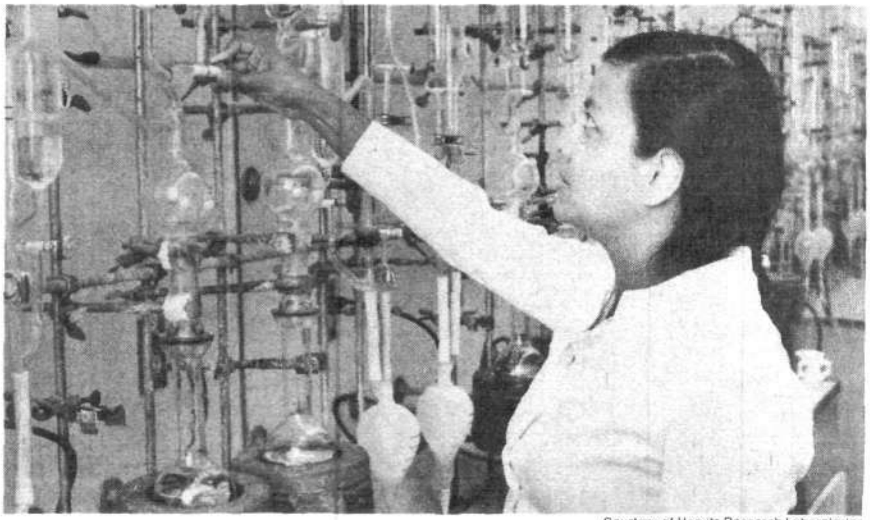


THE HALO EFFECT

According to the hypothesis of Horvitz and Rosaire, hydrocarbon gases are forced upward in dissolved form under the substantial temperature and pressure around underground deposits, creating the characteristic halo effect.

Purvis's initial laboratory work concerned determining the specific fluorescence wavelengths of various crude oils. He found that each of many different gravity crudes has its unique frequency pattern when analyzed using florescence spectrometry. Subsequently in 1977, the U.S. Coast Guard Research and Development Center at Groton, Conn., verified the specific wavelength "fingerprints" developed by Purvis, and incorporated them in the official Oil Spill Identification System, used by the government for positive identification of the source of offshore oil spills.[4]

Once he was convinced that, in addition to the light hydrocarbons, the heavier, aromatic molecules of hydrocarbons also rise to the near-surface through the same principle of microseepage (though not in amounts visible to the naked eye), Purvis began geochemical surveys, using his fluorescence analysis to determine presence of crude oil.



Courtesy of Horvitz Research Laboratories

A technician at the Horvitz Research Laboratories in Houston extracts hydrocarbons from soil and sediment by mild heat treatment with phosphoric acid in a partial vacuum.

Application

The first commercial application of Purvis's fluorescence analysis was in the early 1970s, when it was used in conjunction with a survey done for a large oil company off the shore of Louisiana by Leo Horvitz.

The company was interested in testing Purvis's contention that the heavier aromatic crude oils migrated as did the lighter gases measured by Horvitz. Purvis explains that the company was shocked that the oil did indeed seep as the gas did. After these results, Purvis and Horvitz carried out one of the largest geochemical surveys ever done in offshore Louisiana. It involved 3.5 million acres, and took two seismic vessels six months to acquire the core samples. The survey was underwritten by 22 major oil companies.

Purvis is the first to stress that his fluorescence technique should be used in combination with other analytical methods, including light hydrocarbon analysis, to maximize accuracy.

If a fluorescence anomaly conforms with the same anomaly mapped by light hydrocarbon analysis, this is a strong indication of a subsurface crude oil reservoir. On the other hand, a light hydrocarbon anomaly that does not have a corresponding fluorescence anomaly would suggest presence of gas or a gas-distillate accumulation.

It is very valuable to have such intelligence prior to drilling, as it permits differentiation between oil and gas deposits before costly drilling takes place.

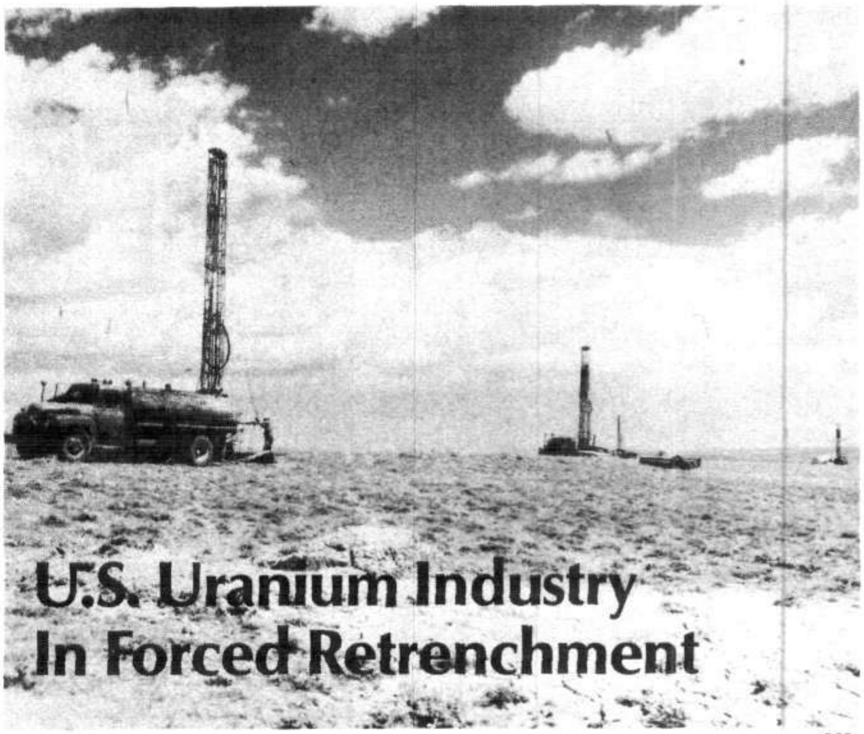
An independent geologist who has had extensive experience using fluorescence data provided by Purvis, Milton Bernos, Jr. of Metairie, La., reports that the data permitted him to determine ahead of time whether a zone was barren, "with 100 percent accuracy." In another survey of 108 wells for a second client, the fluorescence analysis correctly identified the producing wells with 86 percent accuracy.

Given the relative economics of different exploration tools, the development of geochemical exploration can significantly alter world petroleum availability. Nations or regions now economically prohibited from initiating a substantial preliminary testing for possible hydrocarbon resources would have available an extremely rapid and accurate means to determine which basins or parts of basins will be barren or nonproductive. Such "high-grading" of possibly productive areas enables the most efficient delineation of structure necessary before any commitment to carry out test drilling.

The cost of doing this through purely seismic means can be prohibitive. Current charges for a seismic line can run as high as $15,000 or even $20,000 per line mile. By contrast, the cost of running samples for an area of approximately 36 square miles is about $15,000, using random sampling methods and computerized contouring of sample data.

Notes

1. W. Engdahl, "Mapping America's Vast Oil and Gas Wealth," *Fusion*, Feb. 1981, p. 35.
2. L. Horvitz, "Vegetation and Geochemical Prospecting for Petroleum," *Bulletin of the American Association of Petroleum Geologists*, Vol. 56, No. 5, May 1972. Includes relevant historical references.
3. R.G. Talbert, developer of the Electro-Seise electromagnetic mapping technique, reports that in a recent combined survey of subtle geological conditions in Mississippi, the results of a fluorescence mapping were independently confirmed by Electro-Seise. Talbert hypothesizes that microseepage results from the action of the electromagnetic field.
4. U.S. Coast Guard Office of Research and Development, "Oil Spill Identification System," Report No. CG-D-52-77, June 1977.



DOE

Exploring for uranium in the Shirley Basin of Wyoming in 1967, a peak year for the industry. Uranium development was booming in the American West, to keep up with the growth of nuclear-generated electricity.

U.S. Uranium Industry In Forced Retrenchment

Two years of depressed prices, environmentalist blockage, and foreign takeovers have endangered the future capability of the U.S. uranium mining industry, and with it the future of nuclear power in the United States.

Industry sources are predicting that uranium mining capacity will contract dramatically over the months ahead unless something is done to alleviate the industry's problems. The Department of Energy has conducted a study and Congress has initiated its own inquiry. But to date, neither investigation has communicated the urgency the situation warrants.

Price and Production Slump

Surveying the international picture, a recent analysis commissioned by the European Community (EC) calculated that in the 1990s uranium production (noncommunist countries) will cover only half of the combined needs of Japan, the EC, and the United States. Without the reprocessing of spent fuel and the introduction of fast breeder reactors to expand the uranium fuel base, the EC report said, there will be a uranium supply crisis by as early as 1995.

The domestic uranium industry has been hit by a sharp price decline, triggered by a moribund nuclear reactor industry. International prices have plunged from a high of $43 per pound of milled product in 1978-1979 to a recent price of about $25 per pound.

As a result, planned capital investment in U.S. uranium production capacity is now projected to plummet from $515 million in 1980 to less than $195 million in 1982.

Analysts are projecting that by 1990, U.S. production of U_3O_8, uranium oxide or yellowcake, will be about 16 million pounds per year, compared with the 42.5 million pounds of yellowcake mined and milled by the industry in 1980.

According to a top executive of a Colorado uranium company, total uranium milling capacity in New Mexico, Utah, Colorado, Wyoming, and Texas—the core of the industry—has been reduced by more than 36 million pounds from the 1980 peak.

The Grants Belt

The depression of the uranium industry is particularly visible in New Mexico, a state that in 1978 produced 46 percent of total U.S. yellowcake concentrate. The Grand Junction, Colo. office of the Department of Energy estimates that New Mexico holds well over 50 percent of total domestic uranium reserves; in the high-quality, $50 per pound category, New Mexico holds approximately 16 percent of the total assured world uranium reserves in the noncommunist world.

A trend extending in a 30-mile-wide swath running for approximately 100 miles in the northwest portion of New Mexico, the Grants uranium belt, is the single largest reserve in the United States.

This belt has been an important mining area since the 1950 Haystack Mountain discovery near the town of Grants sparked a New Mexico uranium boom. The industry in the Grants belt has been the recipient of major capital inputs from such companies as Anaconda, Kerr-McGee, United Nuclear, and Homestake. There were some 16 major exploration and production operations in the 1970s uranium mining peak in the Grants belt alone. In the last seven to eight years, $1 billion to $2 billion has been invested in mining and related infrastructure by these firms.

Today, however, the area is becoming increasingly depressed. The large United Nuclear facility in Church Rock exists on a day-to-day extension from the New Mexico Environmental Improvement Division, and is operating at only one-third capacity.

The large joint venture of Conoco and Wyoming Minerals Corporation to build an underground uranium mine at Crownpoint closed down last June, two years before mining was to begin. Other firms like Getty have instituted heavy layoffs. Phillips is reportedly getting out of uranium altogether. And Anaconda closed its Jackpile open pit mine last February. Many smaller independent miners, who lease properties from the large companies and are a critical link in the uranium mining process, have been driven out of business by the depressed prices and rising mining costs.

The Crownpoint Case

The price oscillations would not have had such a disastrous impact on the uranium mining industry were it not for environmentalist challenges, a number of which have been financed with government funds from the Bureau of Indian Affairs, VISTA, and other agencies.

One recent case that illustrates the larger pattern was the deployment against the Conoco-Wyoming Minerals joint venture in Crownpoint, N.M. With grant money provided by the Arco-financed Aspen Institute, a handful of self-appointed town guardians and the local Navajo tribe were set on a course to destroy the mining venture.

The leaders of the campaign were ecologist Donald Levering of the Crownpoint Citizens Alliance, a community organizing project; Paul Robinson of the Southwest Research and Information Center; and government-paid lawyers from the DNA People's Legal Services, Inc.

The environmentalists fostered hysteria in the community, alleging that the nearby uranium mines were depleting and contaminating Crownpoint's aquifer. In fact, given the chronic water shortages in the Southwest, the state of New Mexico has passed strict laws requiring that any water depleted by uranium mining must be replaced.

Studies by the Crownpoint environmentalists and a legal-services organization called the Crownpoint Energy Impact Review and Study Committee showed a 50-foot drop in the surrounding aquifer level. However, as the companies pointed out, uranium mining uses extensive water in its "dewatering" phase. But in conformity with state law, Conoco has drilled new water wells that have increased Crownpoint's water supply. The Conoco-Wyoming Minerals project never even entered its dewatering phase.

Economic Losses

As a result of the environmentalist obstruction and related cost escalations, the Crownpoint project will never mine one ounce of uranium. Locally, the Navajo Indians, who represent 50 percent of the mining labor force, will suffer direct job losses. And the Crownpoint case has been replicated in both Colorado and Wyoming.

Substantial untouched reserves of uranium also exist east of the Mississippi, locked up in areas designated as potential wilderness lands.

As the domestic uranium industry is stunted in its development, certain foreign producers, notably Canada and Australia, are positioning themselves to increase their share of the U.S. market. Canada, for example, has recently undertaken major exploration projects in Saskatchewan that will significantly increase Canadian production.

These developments raise the specter of the United States becoming dependent on foreign producers—producers who as parties to the early-1970s international uranium cartel drove up prices from $5 to $40 per pound and disrupted supplies of the U.S. nuclear industry.

As one industry source commented: "If we permit ourselves to become dependent on foreign supplies of uranium, U.S. uranium mining will die on the vine. Hence, we will have painted ourselves into the same corner as with foreign oil dependency: hostage to supply and hold-up tactics on price, regardless of how many nuclear plants we build and operate."

Since 1 pound of U_3O_8 yields as much energy as 10 tons of coal, does it make sense for the United States to allow its uranium industry to be forced out of business?

—*William Engdahl*

DOE

The thickner section of a uranium mill in New Mexico's Grants uranium belt, the single largest reserve in the United States.

Congress Protests Continuing Administration Stall on Fusion

More than a year ago, on Oct. 7, 1980, former President Carter signed into law the Magnetic Fusion Energy Engineering Act of 1980. This law, which mandated that a Fusion Engineering Device (FED) be operational by 1990 and a fusion power demonstration plant be on line by the turn of the century, is now being overruled by the Reagan administration.

Congress, which passed the fusion legislation in a near unanimous vote, has not remained silent on the disregard for its will.

On July 31, Congresswoman Marilyn Bouquard (D-Tenn.) sent a letter to Energy Secretary James Edwards expressing her "dismay and dissatisfaction" at the Department of Energy's effort to stall the engineering phase of the U.S. magnetic fusion program. Bouquard, who chairs the Subcommittee on Energy Research and Production of the House Committee on Science and Technology, also entered into the *Congressional Record* Aug. 10 the report of the congressional fusion advisory panel.

After its June 29 meeting with the House committee, the panel of scientists and industry leaders, headed by Ebasco Services executive vice president Leonard F. C. Reichle, reaffirmed the guidelines and schedules of the fusion law (specifications the panel had helped former Congressman Mike McCormack, sponsor of the bill, formulate).

The new panel report states that "a national commitment to the development of magnetic confinement fusion is essential to the accomplishment of the goals" of the law.

The report notes that the chief problem has been the Reagan administration's refusal to give the go-ahead for the engineering phase of fusion, because of the *future* financial commitment that this will entail. (The establishment of the Center for Fusion Energy [CFE] does not require substantial immediate funding.)

Dragging a program out once its technical risk is considered acceptable is a sure invitation to cost increases.

'Mission Statement' Recommended

The panel recommends that the DOE prepare a "mission statement" for the CFE mandated by the law and that the concept of the CFE include construction plans for the next-step Fusion Engineering Device (FED).

Arguing against defining the technical characteristics of the FED by monetary constraints, not scientific considerations, the report states: "The scope of the FED must be determined by the technical R&D requirements of an overall plan leading to the Fusion Demonstration Plant by the turn of the century, rather than by some arbitrary design restrictions, such as a $1 billion ceiling."

The panel has also taken steps to prevent time-consuming debates over the relative economics of magnetic fusion designs other than the frontrunning tokamak design. The report simply states that "the FED should be a tokamak."

This report by the distinguished scientists and industry leaders on her fusion advisory panel has given Congresswoman Bouquard powerful ammunition against the administration's stalling tactics.

Her July 31 letter to Secretary Edwards reasserted the commitment of both her subcommittee and the full House Science and Technology Committee "to have fusion move into the engineering and technology development phase in as rapid a manner as is fiscally manageable."

Bouquard's letter also addresses the incipient debate over industry's role in the CFE. "The committee has an equally strong interest in involving American industry in a meaningful way with some certainty of a sustaining role," she says, and she calls for industry to be a prime mover in establishing the CFE.

By contrast, a July 7 report from the DOE, mandated by the fusion law, called the establishment of an industry-managed CFE "premature" and recommended that design work on the FED continue in the national laboratories.

Undermining Congress

In summary, Bouquard stated that the DOE proposal "smacks of trying to undermine the congressional idea of a CFE." "Congress has clearly told you they want appropriate responsibility shifted to industry," she wrote, and "[I am] afraid that this administration is not proceeding down the most cost-effective path to fusion power development."

Congressman Don Fuqua (D-Fla.), chairman of the full House Science and Technology Committee, also sent a letter of protest to Secretary Edwards July 30. The focus of his letter is budgetary considerations: "From my years with the space program, I know that dragging a program out, once its technical risk is considered acceptable, is a sure invitation to substantial cost increases, no matter how well or badly the economy is functioning. I hope the DOE will avoid making this mistake with fusion."

Fuqua also emphasized that the establishment of the CFE must precede the FED's construction, and he strongly suggested that the DOE request proposals from industry on a competitive basis to get the CFE going in fiscal 1982.

Two Fusion Experts Leave Gov't Posts

Two key scientific staffers who have helped guide the fusion budget through Congress have resigned from their government positions for jobs with private industry—Dr. Dominic J. Repici, former budget examiner for the Office of Management and Budget, and Dr. Allan Mense, staff member on the Research and Production Subcommittee of the House Science and Technology Committee.

Repici, who was responsible for both the magnetic and inertial fusion programs, resigned from the OMB in August to become the director of corporate development for INESCO, a fusion development company in Washington, D.C. During his four years at the OMB, Repici, who is both a physicist and a lawyer, worked closely with the scientific community to develop the fusion budget.

Mense, a plasma physicist and a nuclear engineer, will leave his post at the end of the congressional session in November to become a senior scientist for the McDonnell Douglas Company's fusion energy department.

Mense was brought on to the subcommittee staff from Oak Ridge National Laboratory by former Congressman Mike McCormack two and a half years ago. At the time McCormack was drafting the fusion energy bill that became law in Oct. 1980. In addition to assisting McCormack in drafting the fusion legislation, Mense has been responsible for coordinating the activities of the congressional fusion advisory panel.

Nominate Scientist To Top DOE Post

Dr. Alvin Trivelpiece, the Reagan administration's nominee for director of the DOE's Office of Energy Research, is a noted plasma physicist

Continued on page 63

Latest Voyager Results Overturn Newtonian Physics

by Dr. Steven Bardwell

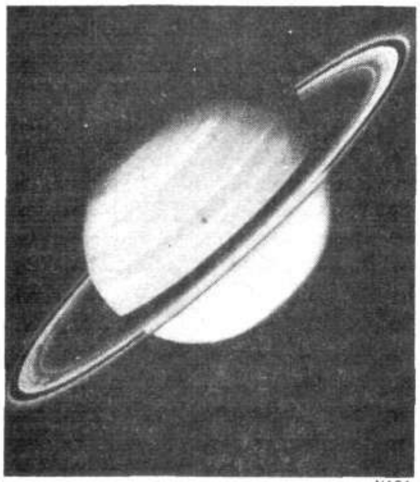
Results from the latest Voyager mission to Saturn have provided scientists with a profound challenge to conventionally understood Newtonian theories of the solar system, pointing the way to a new theoretical basis for astronomy. The newest data, gathered by the Voyager 2 satellite in its closest approach to the ringed planet during the week of August 24, include exciting and unexpected new results concerning Saturn's surprisingly complex ring system, the compositon and formation of its many moons, and the violent "weather" on the planet's surface.

In all these areas, scientists are perplexed by the mass of new data, which contradicts theoretical expectations of astronomers at every turn.

Prior to the data from the first Voyager satellite, most astronomers thought that there were but two rings around Saturn, separated by a theoretically understood gap, the so-called Cassini division. Once Voyager and other satellites provided some extraterrestrial observation, these earlier authoritative observations were revised, and the dominant opinion among astronomers was that there were perhaps 10 Saturnian rings, with a few daring scientists hazarding a guess that there were as many 50.

These scientists were profoundly shocked when the close-up photos provided by Voyager 1 showed that the rings of Saturn were made up of many small rings, with more than 1,000 such small rings discernible. Several predictions were made based on these data, all of which held that the smallest rings had already been seen and that the ring structure itself could be accounted for by so-called scouring action of larger particles in the rings, which cleaned out the gaps seen by the satellite.[1]

It was equally disturbing that the gap predicted by classical theory was found to be only slightly less dense. It was filled with a different size of particle that looked dark when lit from the front by the Sun, but was quite bright (and equally complex) when seen from backlighting.



NASA

Voyager 2, July 12, 1981: Features in Saturn's northern hemisphere and the brightness of the rings have changed since the Oct. 1980 Voyager 1 photographs.

These theories of the role of larger ring particles (called moonlets) in maintaining the ring structure were the basis of much of the data-gathering program for Voyager 2, which conducted a detailed scan of the ring plane to photograph these moons. Not only were no such moons found, but the expectations of scientists concerning the structure of the rings were confounded. As one member of the imaging team said, "The more we have seen of the rings the less we know about them."

The New Findings

The new findings from the Voyager data are fivefold:

(1) Data from a sensitive photopolarimeter, which measured the intensity of light from the star Delta Scorpii as the rings swept in between the satellite and the star, provided a density profile for the rings of a total 43,000-mile extent, with the ability to detect structures as small as 100 meters (200 yards). The 700,000 data points generated by the satellite show new rings down to 100 meters; that is, there are rings on as fine a scale as the satellite could detect. A conservative estimate is that there are at least 100,000 distinct gaps in the rings, generating the same number of rings.

(2) None of the expected small satellites was seen. (Scientists had thought these might account for the gaps.)

(3) The rings showed evidence of a dynamic structure; several rings were seen to coalesce and one new ring was seen to form.

(4) More evidence of compositional differences in different parts of the rings came from spectacular color-enhanced photographs of the rings, as the C ring appeared bright blue and the B ring yellow.

(5) The infamous braided F ring continued to provide problems by appearing to be single-stranded along its whole circumference, even in the neighborhood of the two small "shepherding" satellites, which were thought to account for its spiral structure.

(6) Noncircular structure was observed in greater abundance than expected; density changes, radial spokes, and several noncircular rings were observed.

New Theories

Several theories have been proposed to explain the complex ring structure. According to scientists working on the project, the most popular current theory describes the rings as made up of ice balls that interact with each other through the evaporation and recondensation of water and dust as they orbit the planet. This interaction (similar to the idea of quantum electrodynamics that particles exert forces on each other because of the exchange of real or virtual particles) causes a complex collective interaction in which the resistance to sheared flow (viscosity) of the ring depends on particle size and velocity.

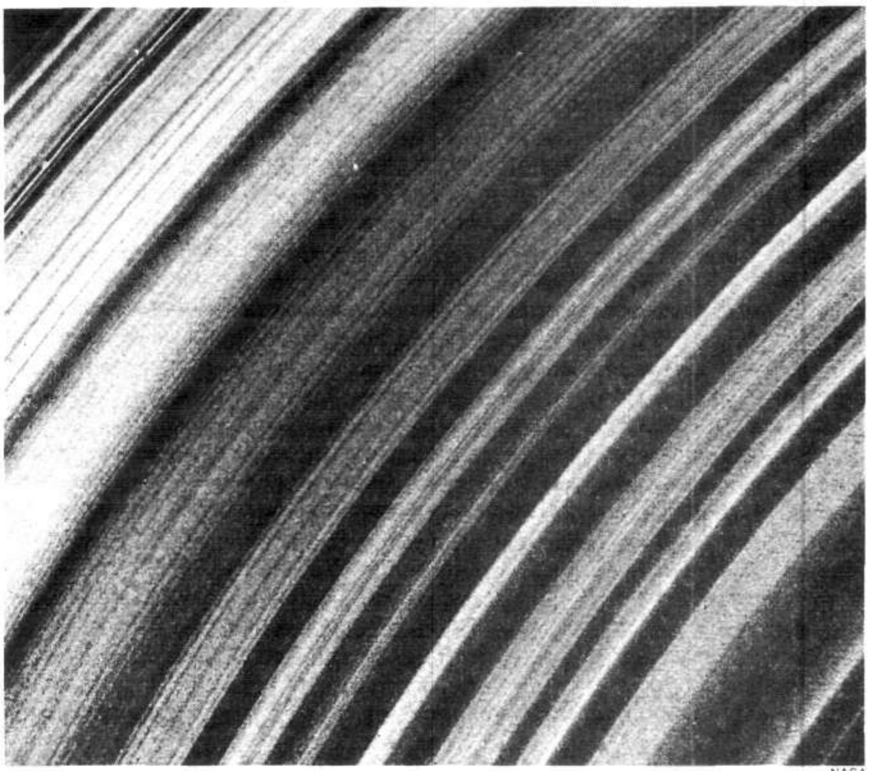
William Ward at the Jet Propulsion Laboratory has shown that under suitable circumstances, which seem approximately valid for the ring system, any initial density perturbations would be amplified, and a sharp edge formed wherever a smooth density maximum appeared.[2] This theory would explain the appearance of the rings only *if* there were some initial density pattern like that observed. Ward's theory would take a weak pattern and enhance the contrast, but it cannot produce circularly symmetric grooves like those seen in the rings.

Several scientists, among them researchers at the Fusion Energy Foundation, have proposed that the complex ring structure is caused by a breakdown of Newton's equations that is similar to what happens in the three-body problem.[3] It is well known that when more than two bodies interact via gravitational forces, a complex and unstable field is set up that can exhibit highly pathological behavior.

This phenomenon, responsible for the difficulty of the so-called three-body problem, might, it was hypothesized, account for the fine structure of the rings.[4] In the same way that iron filings show the structure of a magnetic field, the particles in Saturn's ring would map out the gravitational field.

This suggestion was followed up by researchers J. Avron and B. Simon of Princeton University, who calculated the approximate field around a planet like Saturn, taking into account the fields of its many moons, Jupiter, and the Sun.[5] These authors show that the same instability that afflicts the simplest three-body problem reappears, with the result that the rings have gaps of infinite complexity.

Specifically, they show that the rings will have gaps arranged in a so-called Cantor set—a distribution that has no characteristic scale length and looks the same no matter what magnification is used. Much like the shoreline of a continent that looks equally jagged whether viewed from outer space, an airplane, or from close up (that is, a smaller and smaller section is seen each time, but the jaggedness is always there), the rings of Saturn are predicted to be infinitely divided into smaller rings (until, of course, the particle size is reached). Indeed, one JPL researcher said that he now expects to see rings "down to the individual particle."



NASA

Several thousand of Saturn's rings as photographed in Voyager 2's closest approach to the planet Aug. 25, at 461,000 miles. The narrowest bands here are about 10 miles wide.

A Newtonian Nightmare

This result shows that the rings are a purely gravitational phenomenon, and this provides a critical experiment for traditional theories of gravitational forces.

What is not noted in the Princeton paper is that this theoretical work, together with observation of the rings, provide a deep-rooted demonstration of the inadequacy of the Newtonian approach to gravitational mechanics. In a mathematical sense, the results of the Princeton work show that the gravitational field in which Saturn's rings exist is *indeterminate*. That is, it is mathematically unstable in the sense that a small change in the initial conditions will result in totally different final states.

Like the three-body problem itself, the solutions of Newton's equations for this situation are noncausal. They predict cause and effect to break down at the singularity generated by the multibody interaction. Now, we know that neither the universe nor Saturn is indeterminate or acausal. The rings are not only real, but stable, lawful, and long-lived phenomena. If the mathematical singularity predicted by Newton's equation were the actual description of the rings, we should expect to see a violently disordered system. Since Saturn is obviously ordered, something is wrong with these equations.

The problem is not that the individual particles in the rings do not obey Newton's equations, or that they obey the equations in some different way than do the Sun and Saturn. It is rather that the *causality* of the physical system in question is determined on a different level from that of the individual particles. The so-called collective interactions in the ring have created a qualitatively new structure, which has its own laws of cause and effect—laws that are not mathematically reducible to the interaction of the millions of particles that make up the system. These new laws have yet to be discovered, but results from the moons of Saturn and Saturn's atmosphere point in a provocative direction.


JPL/NASA

Details of Saturn's atmosphere at 2.8 million miles. The dark oval cloud is about 2,400 miles in diameter. The observed flow pattern in the clouds is a result of the varying wind shear.

Saturn's Moons

The newest data from the Voyager spacecraft have provided much intriguing information about the structure and history of the more than 15 moons of Saturn. Most important is the data now available on the composition of these moons. These data seem to show that two of Saturn's larger moons, Hyperion and Mimas, were not created at the same time or from the same material as the other major moons of the planet. Instead, many scientists involved in the project believe that these moons were captured after the planet's formation.

This conjecture would lead to a resolution of a long-standing anomaly in astromony and would contribute a brilliant confirmation of the most important non-Newtonian methodology in celestial mechanics, that of Johannes Kepler. It has long been known that the moons of Saturn obey the so-called Titius-Bode law, a numerical relation relating the distance of orbit to placement for bodies in a solar or planetary system.

In Saturn's case, the Titius-Bode relation is well satisfied by the major moons, except for Mimas and Hyperion. If it turns out that these moons were indeed captured after Saturn's formation, this would causally account for their anomalous characteristics. This demonstration would be a striking verification of the Keplerian geometric method of celestial mechanics, in which the global geometric structure is the determining feature of a system, not the interaction of its individual components. (Newton's equations simply sum up such individual interactions.)

The Titius-Bode law, which is closely related to Kepler's description of the solar system in terms of the Platonic solids, has long been a sore point for Newtonian mechanics; its apparent success is an insoluable paradox. The contraindications to this law, previously provided by Saturn's system, were reassuring to conventional Newtonian conceptions. Now the newest data may prove to turn the tables.

This demonstration of the accuracy of the Keplerian approach points strongly in the direction of the higher-order causality required to describe the ring structure well. Researchers at the Fusion Energy Foundation are currently working on the application of this Keplerian method to the new data on Saturn's moons.

Saturn's Weather

The weather system of Saturn, which was almost invisible to the less powerful cameras of Voyager 1, was revealed by Voyager 2 to contain complex jet stream phenomena, a variety of different storms and storm-generating mechanisms, and long-lived localized disturbances. Voyager 2 provided these data in beautiful detail in both movies and photographs.

These weather patterns have occasioned much comment by the Voyager scientific team, but the team has not emphasized what is perhaps the most startling feature: Despite the greater activity we now observe on Saturn's surface, the results are contrary to predictions of classical fluid mechanics.

According to the classical theory, the more viscous, slower moving, and smaller a fluid is, the more ordered its motion should be. This combination of factors is measured by the Reynolds number, and the general mathematical theory of fluid mechanics says that the higher the Reynolds number of a fluid, the more disordered and smaller-scale the motion should appear. That is, the vortices, wakes, jet streams, and so on that appear should be smaller, shorter lived, and more disordered.

The data from the Voyager satellites showed a surprising comparison between Jupiter and Saturn. While Jupiter has a larger Reynolds number, its flow is clearly more ordered (larger scale and longer lived), and Saturn's, with a lower Reynolds number, is less so.

This result, so contrary to conventional intuition in fluid mechanics, has yet to be explained by or speculated on by the Voyager team, except to note that there are highly complex effects on both planets because of the variability of the Reynolds number with latitude and the very high localized velocities on both planets.

Recent research on an FEF climatological model for the earth sheds some light on the mechanism that might explain the results from Voyager.[6] The FEF team found that the traditional microscopic analysis of fluid flow in Newtonian terms, which results in the equations that give the Reynolds number result, does not suffice to explain the behavior of energetic fluids on the surface of a rotating sphere—for example on a planetary atmosphere. In this case, the fluid creates new "elementary particles" whose interaction then determines the dynamics of the fluid.

These structures, called quasi-geostrophic vortices, resemble large whirlpools. It is their ability to push around each other and other parts of the atmosphere that shapes the long-term weather patterns.

These results are very similar to those required for description of the rings of Saturn or the formation of the moons. It is not that the smaller parcels of atmosphere, which conventional fluid mechanics starts with, do not obey classical mechanics; it is that the result of adding up these smaller interactions is indeterminate: One must look at the macroscopic structures to find the cause and effect relations governing the fluid.

For the atmosphere, this problem seems to have a solution that is already known. The problems for the moons and rings remain.

As I have noted elsewhere in discussing nonlinearity in fusion plasmas, the solution must take into account the fact that no atom can bark—no matter how hard a Newtonian analysis may try to make it do so—but some collections of atoms can.

Notes

1. For example, see H. Henon, *Nature*, 293: 33 Sept. 3, 1981.
2. *Geophysical Research Letters*, 8, June 1981, p. 641.
3. See John Schoonover, "The Changing States of Matter in Supernovas," *Fusion*, Dec. 1980 p. 40.
4. See Steven Bardwell, "Solving the Three-Body Problem," *Fusion* June 1978, p. 21.
5. *Phys. Review Lett.*: 46:1166, 1981.
6. A report on the climatology research appeared in *Fusion*, Sept. 1981, p. 50.

Fusion Editor Bardwell Tours New Mexico Laboratories

"One of the most exciting and important new plasma physics experiments in the world" is how Dr. Steven Bardwell characterized the reversed field zeta-pinch (ZT-40) device at Los Alamos National Laboratory on his recent three-day speaking tour in New Mexico.

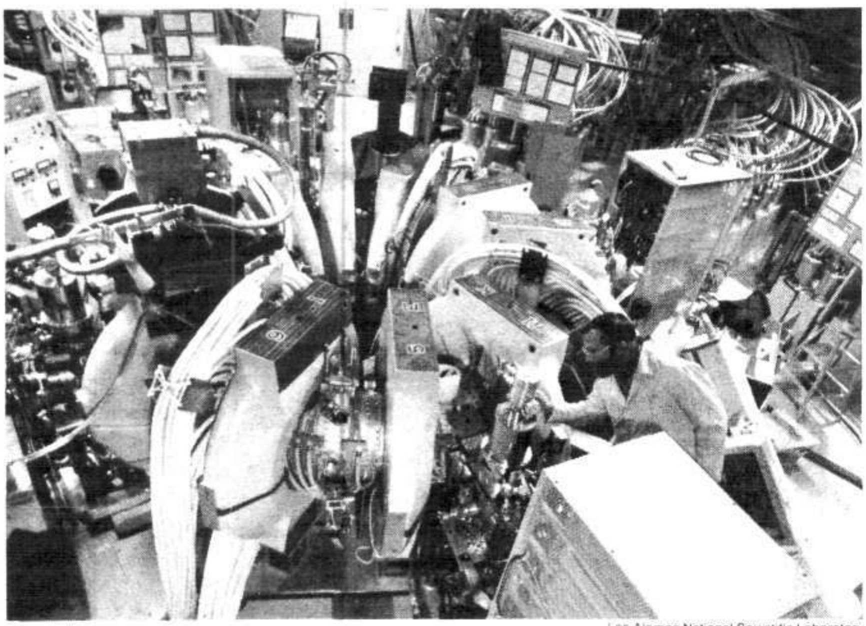
Bardwell, the editor-in-chief of *Fusion*, visited the national laboratory at Los Alamos, gave a colloquium at the University of New Mexico physics department, addressed the university's Associated Students group, and met with FEF members and subscribers in the Albuquerque area.

Bardwell's tour of the Los Alamos National Laboratory began with a visit to the new carbon-dioxide laser facilities, whose ground-breaking work in long-wavelength inertial confinement drivers promises a technological solution to the laser fusion problem.

The high point of the tour was a lengthy meeting at the ZT-40 facility, where Bardwell had a lively discussion about the significance of the astounding new results from the zeta-pinch device. These results, he said, confirm in the most striking way the conjectures that he and other FEF researchers have made over the last six years about the importance of self-ordering phenomena in plasmas and the necessity of letting "the plasma do what is would like to naturally" in order to achieve efficient, stable compression of a fusion plasma.

A Revolutionary Development

"If you were to take the classical examples of self-ordering, like the von Karmen vortex street, or two-dimensional fluid turbulence, and put them in a toroidal geometry, you would have the newest results from the ZT-40," Bardwell said in describing the experiment. "It is without doubt one of the two or three really



Los Alamos National Scientific Laboratory

The ZT-40 at Los Alamos, a reversed field zeta pinch fusion device, whose recent results confirm the importance of self-ordering phenomena in plasmas.

revolutionary developments in plasma physics in the past decade."

In the next two days, Bardwell addressed three public meetings on the FEF's scientific and economic research. Attending the members and subscribers meeting in Albuquerque were what Bardwell described as a highly motivated group of 65 oil men, trade unionists, scientists, and farmers, some of whom had come from as far away as Tucson, Ariz.

"Our four-hour discussion of energy policy, military policy, and economic policy, especially the high interest rates, indicates the depth of opposition in the country to the fiscal and scientific austerity which has come to dominate the Reagan policy," Bardwell said.

The next day, Bardwell gave a colloquium to the physics, astronomy, nuclear engineering, and chemistry departments of the University of New Mexico. The seminar group of 60 students and professors included several researchers from the nearby Sandia National laboratory and the Kirtland Air Force Weapons Laboratory. Bardwell focused on the FEF's recently completed research on the use of strong shock waves for inertial confinement fusion, setting off an animated discussion of the question of optimal pellet design for the new compression mechanisms described in the FEF research.

Levitt Named Editor of Laser Focus Magazine

Dr. Morris Levitt, former editor-in-chief of *Fusion,* has been named editor of the trade publication *Laser Focus.* Oriented to the optical industry, communications sector, and the scientific community, *Laser Focus* is published monthly in Newton, Mass.

Don't Miss The Young Scientist

The third issue of *The Young Scientist,* the FEF's children's magazine, will reach 18,000 subscribers, including 2,000 schools and classrooms for which subscriptions were donated by local businesses and corporations. The cover story is on the Shuttle's next step—colonizing space. Other articles of note are a news story on how smoking marijuana damages brain cells, an interview with former NASA administrator Dr. Robert Frosch, and the story of how two boys built a model tokamak.

Antinuke PR Firm Does PR for FEF—Inadvertently

In August, the FEF issued a dossier on the buyout by Ogilvy & Mather International, an advertising firm whose clients include the World Wildlife Fund, of the company that does public relations for the Edison Electric Institute (EEI), the association of investor-owned utilities. (See "Environmentalists Handle Nuclear PR," *Fusion,* Nov. 1980, p. 58.)

The information in the dossier, uncovered in the course of investigating slanders of the FEF circulated to utility executives, elicited a prompt response. The EEI received calls from members demanding to know, in effect, why "the antinukes are running PR for the nukes."

Five of the companies then called the FEF directly to say that they had made their concern known to the EEI. As a result of the pressure, sources report, the EEI is now reviewing whether to renew its contract with Ogilvy & Mather.

Inadvertant Admissions

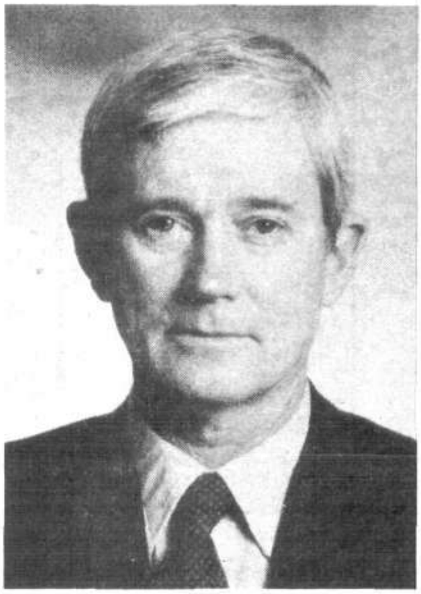
The FEF subsequently learned that Ogilvy & Mather has "counter-attacked" by sending out a letter to the chief executives of hundreds of electric utilities, enclosing the FEF's dossier for reference. The Ogilvy & Mather letter contains three unusual admissions, clearly inadvertent: first, that "several" executives had asked Ogilvy & Mather and the EEI to support and work with the FEF, but that the advertising firm had "resisted" such cooperation; second, that the firm preferred to keep the entire affair "quiet"; and third, that the Anti-Defamation League of the B'nai B'rith was responsible for circulating anti-FEF material to the EEI, which is what the FEF dossier indicated.

The FEF is considering legal action against the actionable slanders in the Ogilvy & Mather letter.

FUSION classified

Classified section advertising rates: $70 per column inch. Width of column 2³⁄₁₆ inches. Ads are available in 1, 2 or 3 column widths. All camera-ready copy must be received by the 20th of the month, and insertion orders by the 13th of the month, one month prior to the on-sale date (which is the last week of the month 2 months preceeding the cover-month). If photo or artwork is in layout, add $20 for non-camera-ready copy. Submit copy for non-camera-ready ads by the insertion order deadline.

Make checks payable to the Fusion Energy Foundation, 250 West 57th St., New York, N.Y. 10019. For more information call Anton Chaitkin (212) 247-8820.



Dr. Alvin Trivelpiece

Trivelpiece

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who is expected to be a strong supporter of an aggressive fusion effort. At present he is a vice president of Science Applications, Inc. in California.

Trivelpiece was a professor of physics at the University of California from 1959 to 1965 and at the University of Maryland from 1966 to 1976. In 1973, he was assistant director of research in the fusion division of the Atomic Energy Commission. From 1976 to 1978, he was vice president at Maxwell Laboratories.

When confirmed, Trivelpiece will replace Carter holdover N. Douglas Pewitt, who has consistently downplayed the fusion effort.

At his confirmation hearings, Trivelpiece stated: "I look to Ed Kintner, director of the DOE fusion program, to provide continued leadership to the program. I hope to back Kintner up whenever he needs backing up. I expect to be able to do an effective job on fusion."

Letters

Continued from page 11

"Rudakov disclosures" work of FEF, and to the FEF's important promotion of relativistic plasma beam antimissile weapons beginning 1977.

Despite those and related facts, the argument has been submitted that FEF ought to abandon the policies through which it achieved its leading position and functions of today. It has been argued that FEF ought to abandon all controversy of the sort on which it had been built, to become fat, lazy, happy, and gregariously useless, amid the dinners-and-cocktails circuits of all good fellows of the proscience community. Sheffield's letter is another argument, in effect, for that "fat and lazy" policy.

The huge brawl centered around leading protagonists Max Planck and Ernst Mach earlier during this century, involved issues of the most profound practical relevance to crucial problems of relativistic plasma physics today. The issue was essentially this. Is the universe *geometric*, as Planck's predecessors from Kepler through Riemann had proven repeatedly? Or, is the universe to be explained on the premise of *hermeticist-numerological* assumptions, as Fludd, Newton, Descartes, Cauchy, and Maxwell illustrate that point of view? Admittedly, the hermeticist viewpoint appears to be the prevailing prejudice among specialists today. Every achievement of the FEF has been premised on our adherence to the view defended by Planck, *or, more specifically*, Riemannian physics.

Truth could not be entirely suppressed by mere force of prevailing opinon. Riemann's physics asserted itself on the superiority of Italy's aeronautical industry of the 1920s, of Peenemünde later, and the lessons of the hydrogen bomb and relativistic plasmas. Riemann's 1859 outline of the determination of shock waves has asserted the superiority of the entirety of Riemannian physics with a vengeance.

The American cowboys, armed with an insufficient supply of lasers, are imminently threatened with being surrounded by Soviet Jndians armed with the more advanced weapons of relativistic plasma beam physics. It has become a leading matter of national security interest, that we push aside Newton, Cauchy, and Maxwell, for the method of Kepler, Leibniz, and Riemann.

Fusion is by no means drooling over the prospect of an early general war. One need not seek war to demand a competent national defense. More directly to the point, the same physics is the physics of tomorrow for any nation not foolishly resolved to decay into the ranks of one of the least developed societies of the future.

It is the FEF's task, as well as its tradition, to contribute to fostering knowledge of the geometric outlook on which adequate progress in physics depends. Admittedly, for the weaker, more easily frightened, it is easier to run with the flock, to pretend to believe nothing that is not at the center of prevailing opinion. It is easier to be such a person, but of how little use such persons are to scientific work.

Lyndon H. LaRouche, Jr.
New York City
Member, FEF Board of Directors

Statement of Ownership, Management, and Circulation
(Required by 39 U.S.C. 3685)

Fusion magazine, publication no. 437370, is published monthly, 10 times a year except March and October, at an annual subscription rate of $20. *Fusion* and the Fusion Energy Foundation, the publisher of the magazine, are located at 250 West 57th Street, Suite 1711, New York, N.Y. 10019. The Editor-in-Chief is Dr. Steven Bardwell; the Managing Editor is Marjorie Mazel Hecht. The owner, Fusion Energy Foundation, is a nonprofit organization.

Extent and nature of circulation, Oct. 1981

	Average no. copies each issue during preceding 12 months	Actual no. copies of single issue published nearest to filing date
Total copies printed	177,617	196,000
Sales through dealers, street vendors, counter sales	53,397	57,234
Mail subscriptions	94,792	111,686
Total paid circulation	148,189	168,920
Free distribution	2,018	2,300
Copies not distributed	3,050	1,964
Returns from news agents	24,360	22,816
TOTAL	177,617	196,000

Atomic — Biological — Chemical
SATURATION!

FUSION's total circulation: 195,000 in September.

Subscriber profile: 90% have college degrees; 30% have postgraduate degrees; 20% are engineers; 5% are scientists; 35% are in management.

(Telephone survey by S & V Communications, Inc. of New York)

Industry Classification of Subscribers in Selected Locations (May 1981)

	Total Subscriptions	Nuclear/Utility/ Advanced energy	Fossil fuel/ Chemicals	Aerospace/ Electronics	Biology/ Medicine	Construction/ Real Estate	Finance Accounting	Other
Massachusetts	2853	260	125	218	180	161	156	—
Connecticut and Rhode Island	2311	221	119	124	107	116	161	—
Long Island, N.Y.	958	80	25	71	44	44	48	—
Metropolitan Washington, D.C.	3536	199	97	165	181	163	171	424 (military)
Southeast Florida	1774	94	42	109	109	158	108	—
Pittsburgh	752	112	49	38	43	28	27	—
Suburban Detroit	1443	70	41	50	95	70	37	154 (auto)
Suburban Chicago	1616	111	97	78	78	67	83	—
Southeast Louisiana	1262	92	326	42	67	60	44	—
Metropolitan Houston	4244	274	1205	206	185	277	194	—
Albuquerque/Los Alamos	817	205	68	48	33	53	26	—
California coast, south of Los Angeles	6944	555	256	750	393	674	357	—
Bay area, below San Francisco	5056	448	154	677	230	412	234	—
Livermore, California area	1803	204	86	85	96	148	81	—
Seattle	1508	64	33	205	66	138	78	—
Tri-cities area, Washington	622	251	16	24	24	47	8	—
Canada	2325	186	248	100	103	101	97	
Mexico (English edition only)	311	37	18	7	14	9	15	
TOTAL subscriptions	107,972	7,723	8,658	6,446	5,841	7,103	5,004	

FUSION magazine has achieved a unique quality and loyalty in its subscriber base because FUSION fights for the highest ideals of American science, ideals that lead to a high-energy, abundant future.

ADVERTISE IN FUSION

Our readers have vision. Let them see you in here.

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NASA

This false-color photograph of Saturn's northern hemisphere was taken through violet and green filters to show a large amount of small-scale cloud activity.

Virginia Baier

The containment vessel of the Seabrook, N.H. nuclear plant under construction.

INDUSTRIALIZING THE MOON

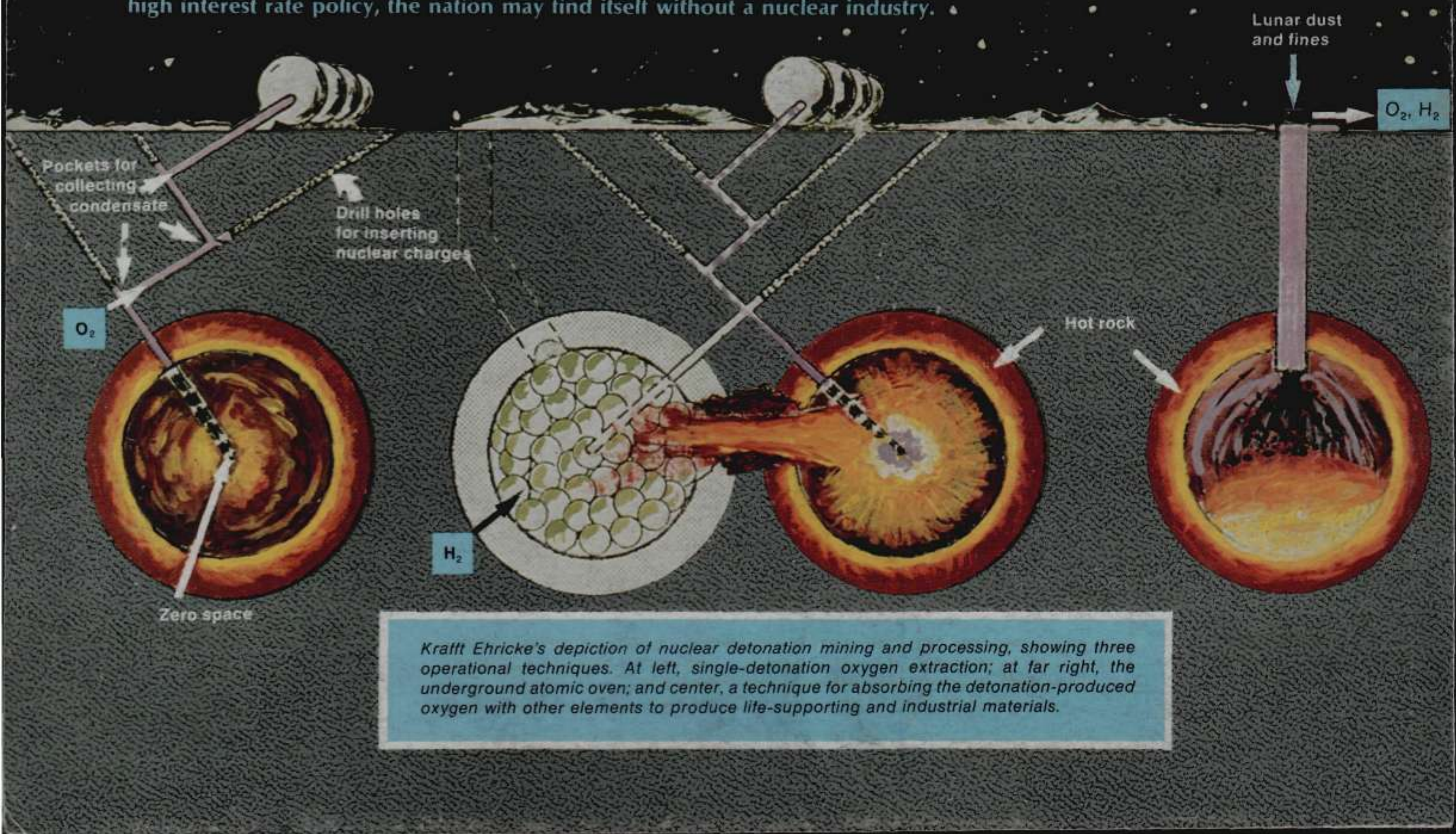
Space scientist Krafft Ehricke's five-stage plan for industrializing the Moon is a definitive rebuttal to the myth of limited resources. In the first of an exciting two-part series, Ehricke demonstrates that there are abundant quantities of exploitable mineral resources on the Moon, and that these can economically provide the raw materials for the polyglobal expansion of human civilization. The product of more than 40 years' involvement in the study and development of space technologies, Ehricke's detailed plan is entirely within the scope of realizable technologies—if there is a renewed commitment by terrestrian governments to joint Earth and space development.

SATURN'S 100,000 RINGS

Voyager 2 has provided us with spectacular new data on Saturn that overturn Newtonian mechanics. As Dr. Steven Bardwell discusses in Science Update, the Saturnian system requires a new theory where the determining factor is the global geometric structure, not the interaction of individual components.

THE U.S. NUCLEAR INDUSTRY: SOME SHOCKING FACTS

High interest rates are doing more damage to the U.S. nuclear industry than the previous 10 years of antinuclear environmentalist attacks. As Lydia Schulman documents in the Nuclear Report, unless the administration reverses the high interest rate policy, the nation may find itself without a nuclear industry.



Krafft Ehricke's depiction of nuclear detonation mining and processing, showing three operational techniques. At left, single-detonation oxygen extraction; at far right, the underground atomic oven; and center, a technique for absorbing the detonation-produced oxygen with other elements to produce life-supporting and industrial materials.