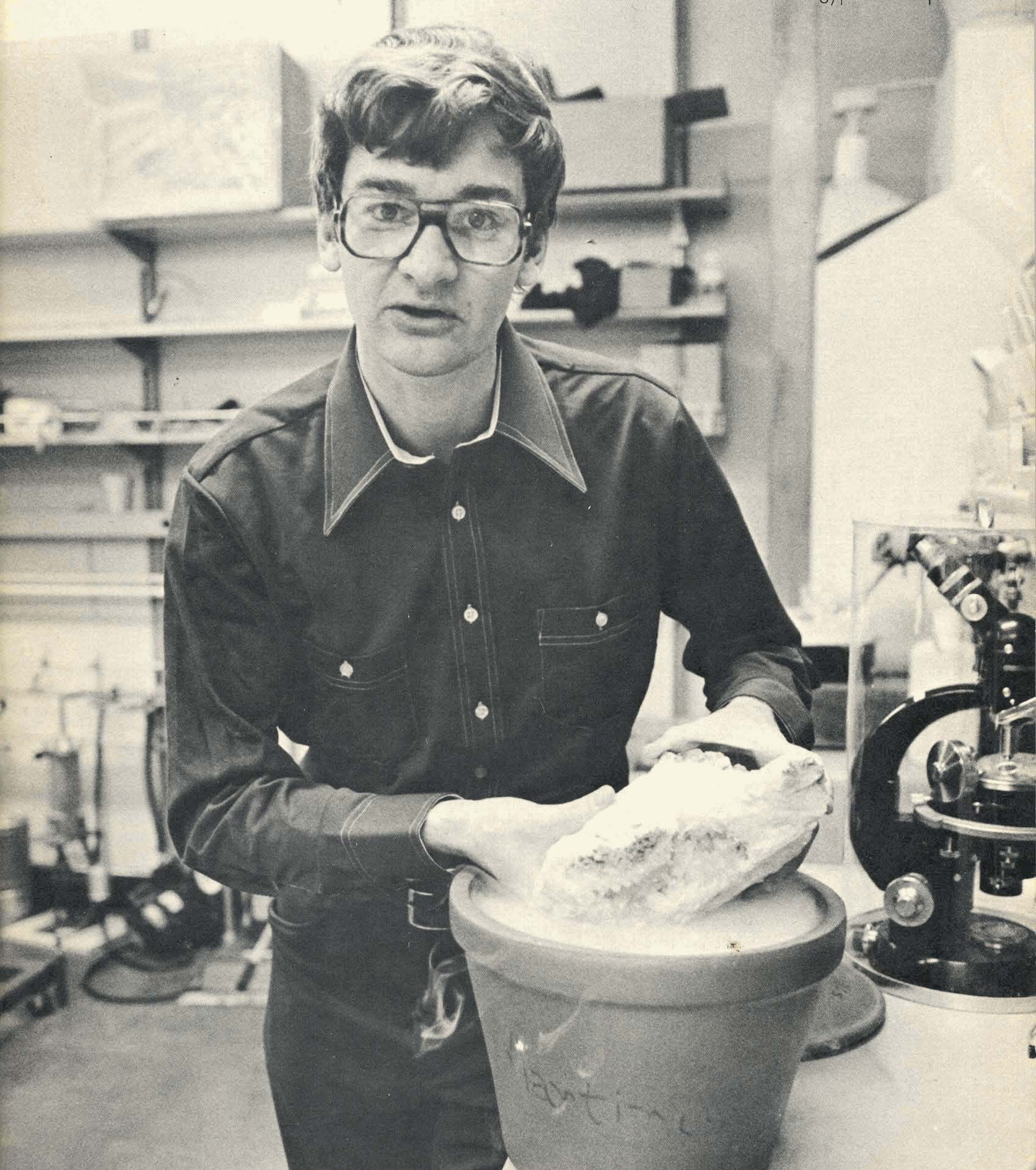
Engineering & Science

California Institute of Technology | March - April 1978



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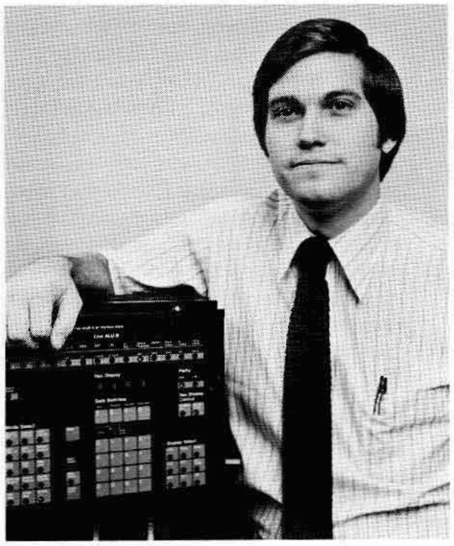

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University of California, Santa Barbara
MS/Electrical Engineering '77
University of California, Santa Barbara
"The technical vitality here at IBM is attractive for young engineers looking for a future."

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"Career achievements are not determined by competition between individuals but by the capabilities and ambition of each individual."

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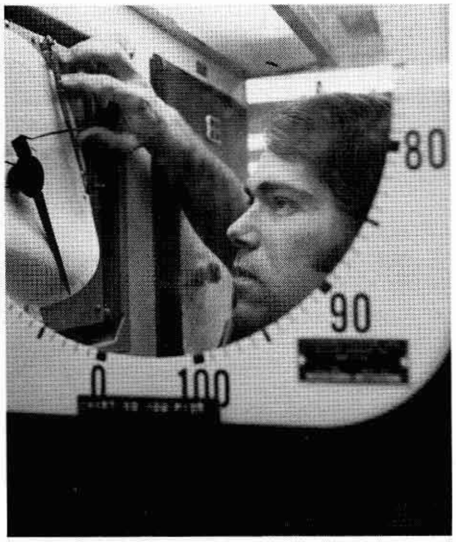
"The atmosphere is relaxed and informal, quite distinct from the dark suit and tie image of IBM. The people as a whole are congenial and cooperative."



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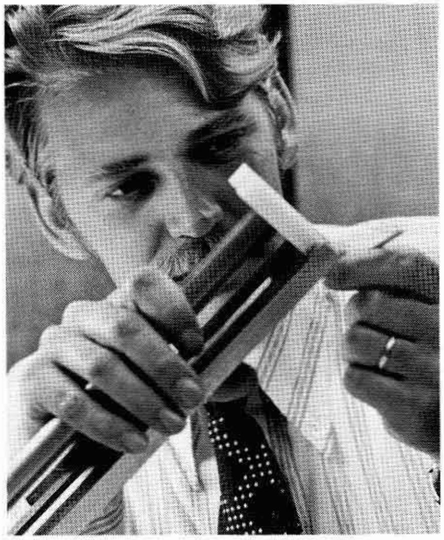

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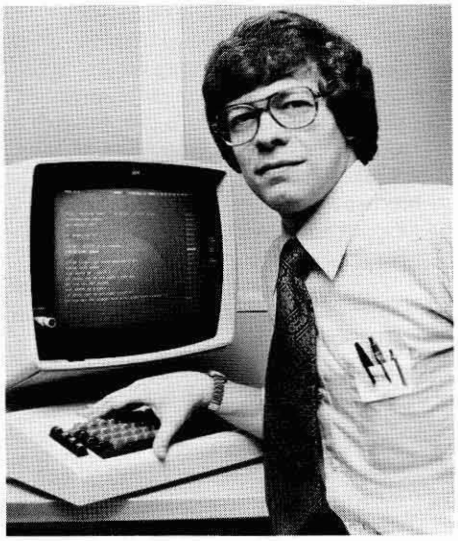
"IBM has elevated my responsibilities as fast as I was willing and able to accept them."



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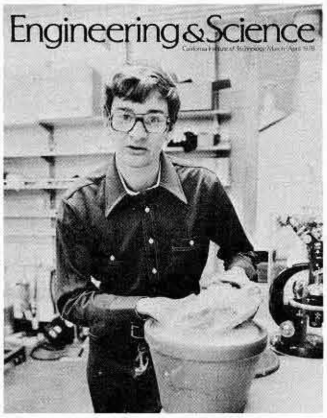
In This Issue



All That Glitters

On the cover—George Rossman, associate professor of mineralogy, is investigating the physical properties and structure of a mineral sample. Specifically, he is studying a sample of calcite, with the aid of some CO_2, or dry ice. Rossman's scientific interests are in the interaction of electromagnetic radiation with minerals, which means his studies involve reactions with light, magnetism, and heat radiation. Since these studies usually require minerals that are free from imperfections, Rossman works frequently with gems—about which he has become something of an expert, as evidenced by "Glitter: Gems or Gyps?" on page 26.

The article has been adapted from a Watson Lecture given by Dr. Rossman in Beckman Auditorium on February 15.

World View

Looking the world over is something Bruce Murray, director of JPL, has had a lot of practice doing—only partly as a planetary scientist observing what's going on "out there." He is also deeply concerned with what is going on right here. Increasingly, he is thinking, writing, and speaking on the nature and quality of life on earth.

About a year ago, *E&S* published Murray's article on what the place of technology is going to be in our lives. Zeroing in on one aspect of that topic, he recently gave a Watson Lecture entitled "Solar Energy: True God or False Prophet?" On page 4 is an adaptation of that talk.

Moon Magic

It may look like a carton of cottage cheese in the hand of Caltech alumnus Noel Hinners (MS '60), but it isn't. No earthly substance could command such undivided attention from these three men. Inside the container are two one-half-gram samples of lunar soil collected from the moon's Mare Crisium by the unmanned Soviet spacecraft Luna 24. They are the first of seven samples from that mission released by the Russians for study by American scientists.

With Hinners are two other Caltech alumni—in the center Michael Duke (BS '57, MS '61, PhD '63), and on the left Bevan French (MS '60). All three are with NASA and are vitally interested in the knowledge gained from the space program in general and in what we are learning about the moon's composition in particular. In fact, Bevan French, who is NASA's Program Chief for Extraterrestrial Materials Research, recently expressed his interest by writing *The Moon Book.* This is a highly readable summary for the layman about what man has learned so far by going to the moon. "The Moon and Beyond" on page 12 is an excerpt from the last chapter of that book.

Japanese Future

"Michio Nagai," said Harrison Brown, who introduced him at The Next Eighty Years conference last April, "is an extraordinary man. For example, he was, I believe, the first nonpolitician ever to be appointed Japan's Minister of Education.

"Dr. Nagai was a youngster in Japan during World War II, and he remembers vividly the events of that time and the reconstruction. After the war he was one of the first Japanese students to come to this country, and he has since spent a great deal of time here. He took his PhD in sociology at Ohio State and has taught and done research at Stanford, Columbia, and Berkeley. He has also done research in Mexico, and he was an early visitor to Red China.

"He is the author of a number of books, including *Higher Education in Japan,* which has the intriguing subtitle *Take Off and Crash.* He has also written *Indoctrination and Education* and *An Hour Before Dusk.* In each he has eloquently expressed his concern for mankind."

That concern was also eloquently expressed in his talk at the conference. "The Future of Japan: Continuity and Discontinuity in Social Change" on page 19 is adapted from that talk.

STAFF: *Editor and Business Manager*—Edward Hutchings Jr.
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PICTURE CREDITS: Cover—Richard Kee/2, 24—Floyd Clark/2, 12-18—NASA/24-25—Robert Paz/32 Graphic Arts.

Published four times a year, October-November, January-February, March-April, and May-June, at the California Institute of Technology, 1201 East California Boulevard, Pasadena, California 91125. Annual subscription $4.50 domestic, $5.50 foreign, $11.00 foreign air mail, single copies $1.25. Second class postage paid at Pasadena, California, under the Act of August 24, 1912. Published by the California Institute of Technology and the Alumni Association.

Engineering & Science

March-April 1978/Volume XLI/Number 3

Engineering&Science
MARCH-APRIL 1978

Solar Energy: True God or False Prophet?

by BRUCE MURRAY

Solar energy is not a "Johnny-come-lately" subject at JPL. Members of the staff anticipated the first public recognition in 1973 of the energy crisis. Several years before, they had identified technologies developed for space use—particularly silicon panels used to convert sunlight into electricity for spacecraft—which could provide important energy uses on the ground, if they could be manufactured much less expensively. A pioneering program was started early and has grown now into a major national activity.

Energy research and development—especially solar energy research and development—now account for about one-seventh of JPL's total activity. Because solar *electric* energy is not yet commercial, an appropriate industry does not exist. So it makes sense for JPL as an advanced technology laboratory working under federal sponsorship to try to create new solar technology and identify how it might fit into new energy production and consumption patterns in the future. Surely, it is a proper role for JPL as a part of Caltech to be responsive in this way to important and practical national needs.

I am not going to make predictions about the future degree of solar energy utilization. I do not believe that is possible. About the only thing that is highly probable is that there will be a massive change in the sources of energy that light our rooms and heat our buildings. Beyond that, technological development is quite open, and therefore the proper posture of the United States is to pursue a variety of diverse possibilities rather aggressively, letting the "strongest" win, so to speak, down the road.

We are all aware that the use of energy throughout the United States and the world has been growing at a very rapid rate, primarily through the greatly increased use of oil burned to produce electricity. Oil is a limited natural resource for the whole world, and we are going to "peak out" in its production around the end of this century.

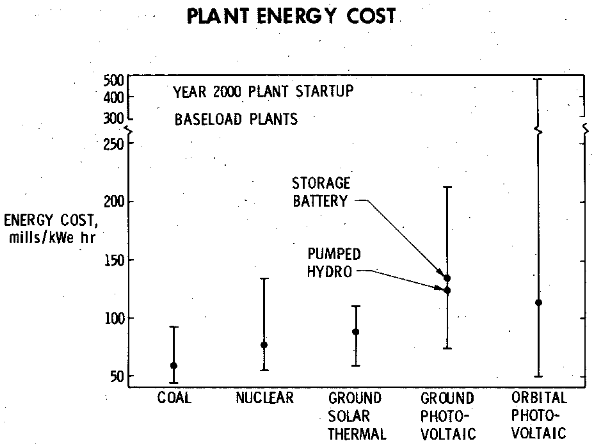
THEORETICAL POTENTIAL VERSUS PROBABLE COST OF SOLAR ENERGY

Could solar energy provide enough electricity and heat to take care of the energy needs of the country, or of significant fractions of it? Theoretically, yes. For example, if appropriate kinds of solar collectors were installed on every roof in the San Fernando Valley, most of the electricity and most of the heat required for that whole area could be generated.

But if we have an energy problem and solar energy can at least theoretically supply a significant amount of what we might need, why isn't it national policy to place its development as our highest priority?

The answer comes from an analysis of what it will cost. Because electricity and gas are distributed by utilities and heating oil is sold by large corporations, the economics they face in making new investments in energy systems are very important to what decision actually will be made. Hence, there is considerable effort at present to forecast the costs and other factors that energy supply institutions will actually face in the next several decades.

The illustration above shows one such attempt. This graph (which exhibits a strange-looking scale because it doesn't start at zero and is compressed at the top due to the scatter of the data) was prepared by JPL people who believe in solar energy production. So it is



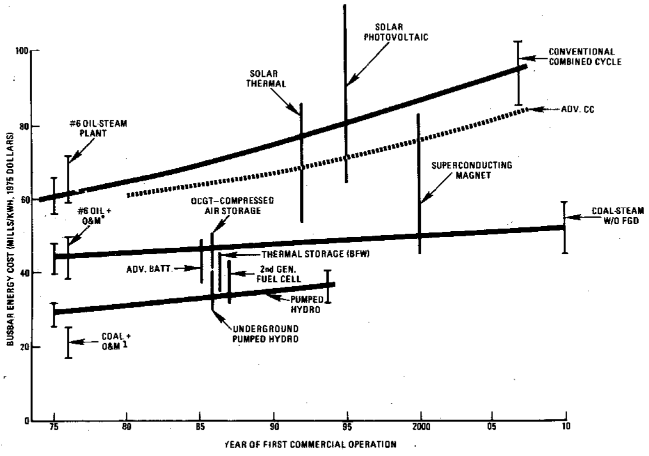
certainly not negatively biased. The units here are the cost of energy in kilowatts per hour. Fifty units or so are assigned for coal. The figure for nuclear is a little higher. Ground-based solar-thermal electric is comparable to nuclear. Photovoltaic production of electricity, which is the program in which JPL is most heavily involved at the present time, is somewhat higher yet. And finally, space power (orbital photovoltaic) could easily cost ten times as much as the ground sources. In this analysis, done by a group that is certainly concerned about the potential of solar, space power doesn't compare terribly favorably.

For comparison, at the right is a portion of a graph prepared by a very reputable national company. They considered quite a variety of technologies in order to try to develop a recommended "investment" strategy for the federal government. Their graph shows the same units along the vertical axis. The horizontal axis is now time, and it refers to when each new technology might be introduced. The solar-electric costs shown here are not much higher than those of JPL; the unit cost of electricity by solar would be perhaps a factor of two higher than it appears to be by coal. Yet that leads this company to recommend a massive exploitation of coal to provide both electricity and heat for the country as oil runs out; solar energy was not deemed very significant.

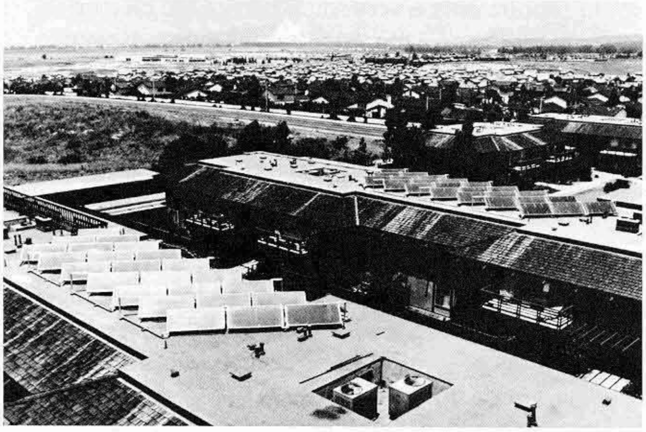
Their reasoning about how useful the billions of dollars that the government is going to invest in new energy technologies depends in part upon how much of a market those technologies finally capture. Because of the difficulty of providing storage or additional base electric load supply in conjunction with conceivable solar electric generation, they assumed solar energy would capture only a very small part of the electric power market, and even then, only at a distant time in the future. Hence, solar electric technology was just not attractive even though the direct cost differences were within a factor of two of, say, coal. They did not envision how solar-electric could fit in practically since solar-based electricity is only produced when the sun shines.

Thus, there really is a national debate revolving around a genuine issue of whether solar energy can be competitive in terms of what are called "utility" costs. This basis of economic comparison attempts to estimate what a utility would have to pay to install and use such technology, and therefore what they would have to charge the user—You.

Now, I am going to argue that these costs and this way of analyzing the situation may not be broad enough to reach sound national judgments. In fact, solar-electric development may be a very important option for the future because there is more to consider than just the cost that may be projected for the utility to pay in a totally unconstrained situation. What is really involved is the *total* cost that society pays, which includes pollution, health, and many other effects. I am also going to argue that, despite all our talk, we are not now operating as a free market for energy supply; we are headed in a direction in this country which may make it impossible in the future for individual companies, or even cities—much less individuals—just to go out and buy energy in the marketplace. Instead, we may be moving toward an allocated society, and if so,



Utility cost versus likely time of first commercial operation for a number of potential new electric-generation technologies, as estimated in a recent federally funded study.



Simple collectors of sunlight are used to heat water in a housing development in El Toro, California.

that also invalidates the utility differences. A third factor is that in some places like California solar energy may fit in very well. In other parts of the country that may not be the case.

SOLAR TECHNOLOGY

How do you capture solar energy and convert it into heat or electricity? First of all, solar energy comes in two forms: direct—sunlight, which can then be used to heat or generate electricity; and *indirect*—wind energy and hydropower, for example.

I am going to discuss the direct forms. With collectors, sunlight can be used directly for heating or cooling. It can be used to enter into chemical reactions with water and other substances to form essential chemicals (hydrogen and ammonia, for instance), though not competitively at the present time. And finally, sunlight can be used to produce electricity either in the same way we do in space (which is to let it fall on silicon or other materials that convert the light directly to electricity) or to collect and focus the sunlight to heat and drive a steam turbine or some other device that converts heat energy to electricity.

Let's run through the technologies, starting out with solar heating. In a housing development in El Toro, JPL and the Southern California Gas Company have been experimenting with simple collectors of sunlight to heat water. The heated water feeds into the hot water system for an apartment building under study, reducing the amount of gas required for hot water heating. This is one of the simplest, easiest, and earliest utilizations of solar heating in California.

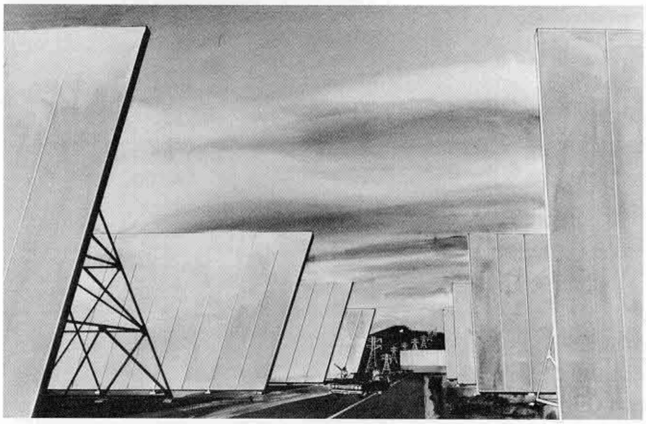
Another type of solar heating now developing (it has been done for years in a small way, but it appears now that it may have applications throughout the United States) involves placing similar collectors on rooftops to heat water which is then used to heat the air to heat the house. These collectors generally would be supplemented by gas or electrical heaters to provide for times when there is not enough sunlight to keep the water (and air) sufficiently hot.

Solar heating is also being used for dehumidifying office buildings, drying agricultural products, and for some industrial processes that need relatively low temperature heat.

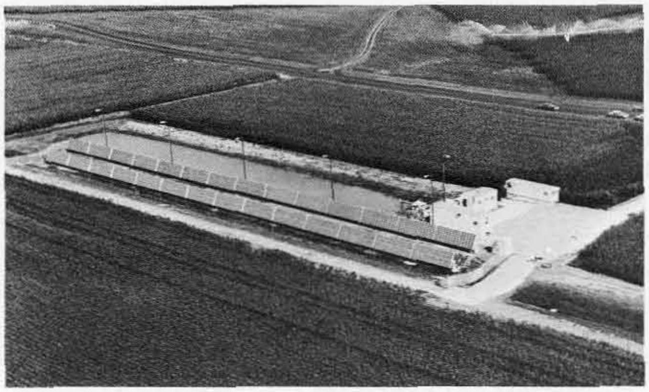
These kinds of applications are all decentralized. There is no big steam plant at the center. It's all done at the site—at the residence, at the apartment building, at the office building, or at the factory. The solar heat energy supplements, but does not replace, gas or fuel oil or utility electricity because there obviously can be cloudy days or conditions that will prevent this kind of system from *always* meeting the needs of the users.

The other major method of using the sun to convert its energy to electricity is by using a "Power Tower"—a prototype system being seriously considered for construction near Barstow, California. This approach would utilize a field of mechanically driven mirrors to reflect the sunlight up to a single focal point, which becomes very hot. That heat is then used (instead of coal or oil) to run a conventional steam turbine.

Such a complex system is very expensive and only becomes attractive on a substantial scale. An alternative method would be to take a lot of smaller collectors, each with its individual devices to transfer converted



Large fields of photovoltaic cells like those in spacecraft may some day serve as small electrical power plants.



On a Nebraska farm, photovoltaic cells convert sunlight to electricity, which is used to run irrigation pumping.

sunlight to electricity, and build up an array. There are advantages of scale in such a large system.

The attractiveness of smaller collectors is that they can be built in an assembly line and installed in modular fashion and begin to produce electricity shortly after manufacture. Hence, the financial risk of long construction delays that any large system (such as nuclear or the Power Tower) has is alleviated; return on investment can be obtained quickly and the system permitted to grow naturally to its most efficient size. There are limits to the application of economies of scale in the energy business. These are only gradually being defined in nuclear energy and are quite uncertain for future solar-electric applications.

A third way to accomplish the same thing is to use photovoltaic cells like those in spacecraft, which should be relatively inexpensive in the future. One would simply aggregate large fields of them to build up what amount to small electrical power plants. But, even though they take up a large area to collect sufficient sunlight, they will still equal in total power output only a small oil- or coal-fired power plant.

Photovoltaic cells can also be used in smaller and dispersed aggregations at the point of use. In Nebraska, for example, sunlight is converted to electricity with such cells, and that electricity is then used to run agricultural irrigation pumping during the day when the sun is out. It can, of course, be supplemented by regular powerline electricity coming from a local utility.

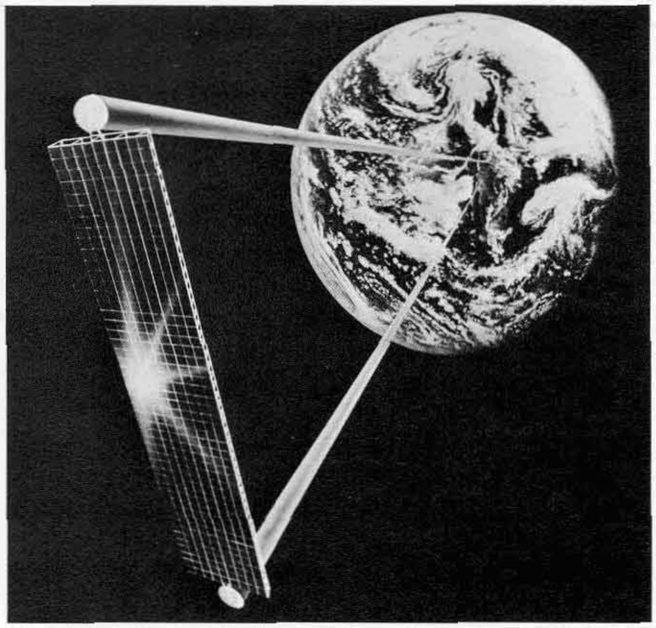
Going to even smaller sizes, there are aluminized collectors, each with an evacuated tube in which steam is generated by the heat of the sunlight. The sunlight is reflected, and it can run smaller turbines. This is a technology that existed in 1900, incidentally. It is nothing new. One can aggregate these, also.

Silicon cells are round and very thin, because they are sliced off from large single crystals—which is intrinsically an inefficient way to make them. The only way they are going to be really useful in the future is if they are much cheaper. There are a good many activities going on right now to learn how photovoltaic materials can be manufactured continuously on a large scale.

In general, everything I have discussed here is low technology. Compared to flying a rocket to Uranus, or compared to the complexities of the breeder reactor, solar-electric technologies are relatively simple and straightforward.

Of course, the electricity from the devices is only produced when the sun is out. Therefore, either there must be on-site storage to provide electricity at other times, or the facility must be tied into a central utility —that is, have an electric wire from the local utility, which is providing base load electricity from burning coal or some other method. One of the reasons the graph on page 5 showed solar as so unpromising a return on the investment is because it is not imagined that it can ever operate entirely by itself. It will always have to operate in conjunction with other *reliable* kinds of sources of electricity. And that runs the cost up.

One concept of solar technology that has received



A 75-ton space power station (25 x 5 km, with a 1-km antenna) could produce 10,000 megawatts of electricity.

POLLUTANTS
CENTRAL POWER PLANTS per MWe per year

	AIR	WATER	SOLID
SOLAR THERMAL*	~8 tons PARTICULATES, NOx, CO	-	-
PHOTOVOLTAIC*	~11 tons MOSTLY PARTICULATES	~2 TONS MOSTLY C. O. D.	-
COAL STACK SCRUB	30-100 tons OF PARTICULATES, NOx, SOx, HYDROCARBONS, CO, METALS	UP TO 55,000 tons ACID; UP TO 8 tons SUSPENDED COAL; UP TO 5.4 tons SLUDGE; NO DATA ON ORGANICS, etc.	1875-2316 tons, NON-RADIOACTIVE SOLIDS
NUCLEAR PLUTONIUM LWR	~1.65 tons NOx, SOx; 4.7-600 curies OF RADIOACTIVES	260-4230 tons OF NON-RADIOACTIVES; 0.1-4.5 curies OF RADIOACTIVES	105,000 tons NON-RADIOACTIVE; ~1600 liters OF RADIOACTIVES

*FROM EQUIPMENT MANUFACTURE ONLY

NO DATA ON SOLAR POWER SATELLITE

a lot of publicity is the space power station. In this case, there would be huge dishes out in space. They would collect sunlight and make electricity, which would then be converted to microwave power and beamed back to earth by an antenna. One drawback is that this conceptual station could be ten miles or more in dimension. Something on this scale could produce large amounts of electricity. It would tap sunlight that does not hit the earth, so it is an additional energy source. Most of the heat and by-products would be dissipated in space and not on the earth, and that has some value. But the costs would be enormous, and they are all front-end costs—that is, they have to be paid for in the beginning, like those of the breeder reactor or other very large nuclear developments. In addition, of course, this technology isn't proven at all.

TOTAL SOCIAL COSTS VERSUS UTILITY COSTS

What about pollution? Is solar energy really cleaner than other sources of energy? Indeed it is. Suppose we compare a solar-electric generating system with coal-fired systems (using a stack scrubber, as it is called, to remove the sulfur and some of the other noxious compounds), and also with a nuclear reactor (a light water reactor using plutonium). In this comparison all the air, water, and solid pollutants will be considered including the mining and manufacturing phases. With solar thermal, for each megawatt of electricity generated annually, there will be about 10 tons of air particulates produced, along with minor nitrous oxides. These emissions include what is involved in the manufacture of materials, not just what is involved in using them to produce solar energy. The total environmental effect is one of the social costs about which we should be concerned.

The coal-based system, for each megawatt of electricity per year, produces something like 100 tons of airborne particulates and substantial amounts of sulfur dioxide and nitrous oxides. In addition, tens of thousands of tons of acid can be expected to be released into the water system along with more modest amounts of suspended coal, sludge, etc. In addition about 2000 tons of solid waste is also to be expected. And the federal government is talking about creating thousands and thousands and thousands of megawatts per year of new coal-based power generation. That pollution will be piling up somewhere, either where it's mined or where it's burned.

In the case of nuclear, there are large amounts of non-radioactive solid wastes as well as radioactive tailings from mining uranium, and small, but serious amounts of other kinds of radioactive debris. Those constitute the well-known problem of nuclear waste, but it is important to recognize that burning coal also has very large environmental effects. The total social cost of extraction and transfer, as well as the burning, of coal has to be included in those effects.

I cannot say how much air, water, and solid waste pollution cost in dollars, because we cannot reduce everything to a monetary base, but there is a real cost. There are the public investments involved in these various things. There are a lot of health effects. For example, in coal mining there is black lung, as well as other diseases. There are certain public health effects caused by breathing the material that comes from the burning of coal. Those have direct costs, in terms of health insurance premiums and lost worker productivity. They also have an intangible cost to the people who get the diseases. Even if one can pay the costs of illness, it doesn't make being ill any nicer.

There is also the impact on our resources. There is a limited amount of land. There is a limited amount of water. There is a limited amount of capital. There are things that must be allocated by the society and they have to be accounted for somehow.

We have to worry about climatic effects that may be created by the burning of large amounts of coal. The burning of coal or any other fossil fuel releases tremendous amounts of carbon dioxide to the atmosphere. The global carbon dioxide concentration *is* building up. At some point that will cause climatic effects. We don't know exactly when, but sooner or later it *is* going to be a problem. A climatic effect would be a lasting problem, like the nuclear one.

Another concern about coal is the large amount of sulfur that is burned; much of it ends up as sulfuric acid. Sweden suffered for centuries because England was burning coal and the winds were carrying the acid clouds to Sweden.

Besides environmental and health factors, there are others. For instance, President Carter has been very concerned about the diversion to the production of weapons of nuclear material, and that is a principal reason he opposes the breeder reactor development.

There are genetic effects from radioactive material and also from some of the other pollutants that emerge from burning of fossil fuels. These are all part of the total social costs.

Of course, one cannot quantify those intangible costs. One cannot say how much the environmental damage is worth, or how much a health effect is worth, or how much the use of land costs. Hence, it is argued that we will still have to use utility costs as the guideline for the development of new energy technology.

But I think that is not true. I think the fact is that some economists cannot quantify those costs, and therefore they tend to think solely in terms of utility costs. But the Congress does not, and the President does not. This total social costing by elected officials shows up as government regulation and taxation policies. So there is, in fact, an attempt made by the political process to grapple with things like strip mining of coal, air pollution standards, and nuclear waste licensing requirements. The intervention of the federal, state, or local government, in the form of regulation, is really an attempt to respond to all those factors that cannot be dealt with strictly by the marketplace cost of a new energy technology. This is a very imprecise process, and it becomes very confused. The process gets mixed up with other social questions such as redistribution of income, and overall doesn't work very precisely by some people's standards. But it is there.

Oddly enough, the people who are developing new energy technology have not always acted as if they understand the political process in reconciling public attitudes about total social costs. The nuclear energy business is an outstanding example, I think, because the arguments for early widespread introduction of nuclear power reactors were based strictly on utility costs. It was recognized, of course, that there were side effects from waste disposal and, hence, widespread concern about pollution and exposure to radiation, and also about the possibility of sabotage or illicit weapons

TOTAL SOCIAL COSTS

UTILITY COST

Cost of materials, capital, labor, fuel, taxes, insurance, etc. for every system
- Central plant
- Transmission
- Distribution

RD&D

Public investment for research, development and commercial demonstration

HEALTH

Cost of public and occupational health due to:
- Mining
- Fuel upgrading and transmission
- Material acquisition
- Construction
- Plant operation
- Final waste disposal

RESOURCES

Resources consumption such as:
- Material
- Fuel
- Manpower
- Land
- Water
- Capital
- Communication frequency
- Geosynchronous sites, etc.

ENVIRONMENTAL

Environmental residues such as:
- Gaseous
- Liquid
- Solid
- Waste heat
- Others

OTHER
- Sabotage, blackmail
- Material diversion to weapons
- Time distribution of impacts
- Local or global climate effects
- Acid rain
- Genetic effects
- Non-renewable material use
- Land use
- Construction impacts

production. But since nobody knew how to confidently quantify those things, they tended to be ignored by the planners—including those of the government and the utilities. What has happened instead of early widespread use of nuclear reactors is that legislation was passed that makes it very difficult to build nuclear plants. So the *real cost* to the utilities of a new nuclear plant is now enormously greater than that forecast ten, fifteen, or twenty years ago. I feel there may be genuine parallelism in the current "bandwagon" for rapid expansion of coal utilization as the panacea for our energy needs.

It is particularly significant, I think, that the solar technologies on the ground have very few bad side effects from the point of view of society. That is my first point in trying to respond to these cost comparisons—that the "utility" cost comparisons are insufficient and that, in fact, society really does try to deal with total social cost. It may appear now that coal is significantly cheaper, but if the mining, transportation, and combustion of coal is increasingly deemed to be harmful or undesirable, then the projected "utility" costs may mean little if the government puts air pollution standards and extraction and transportation regulations on coal that require expensive additional technology to meet.

Another example will show what happens when total social costs get involved with other social questions—like redistribution of income. There has been a bitter battle going on in the Senate over natural gas pricing—a keystone of President Carter's energy bill. The argument is whether or not the government should continue to regulate the price of natural gas that is moved between states. Natural gas used to be an unwanted by-product of oil. It was burned off at the wellhead. It was free initially and eventually became useful as an additional energy source. Gas became regulated primarily for market purposes having to do with the needs of the suppliers for predictable pricing. Suppliers now want to deregulate natural gas (which means to let its cost rise to what it should cost compared to other sources of energy—a factor of two or three more than its present cost) and say, "Higher prices will be an incentive to find more natural gas, which will increase the supply." Those representing gas importing consumers say in answer, "No. Allowing the price to go up is in effect a regressive tax, which means everyone has to pay for it, and that is unfair to the people with the least income. Instead, we should allocate it in some fashion."

Both kinds of statements miss the energy reality this country faces. I feel that the price of natural gas should be increased to its energy replacement cost so as to *cut down* on the use of natural gas because there is a finite amount of it. There is no doubt that eventually we will use every last bit that can be extracted. Only the time scale is uncertain by a few decades. As the price goes up, that will tend to cause people and institutions to use less and to look for alternatives. And, as the price goes up, it makes other sources of energy—such as new solar technology—more attractive for investment and development.

ENERGY ALLOCATION INSTEAD OF FREE MARKET PRICING

That is the right reason to let the price of gas go up. But that right reason gets caught in the political turmoil, and instead we have this great big, almost theological, debate going on nationally which is really over redistribution of income. What is happening in the United States now, in my view, is that we are abandoning the free market in energy pricing. The market is being controlled, partly by the government, and it is pretty obvious that it's going to *continue* to be controlled. If the availability becomes really rough, we'll ration the stuff; we'll allocate it, because we can't seem to solve this political debate in terms of a national long-term energy policy.

We are moving toward a society in which, at least in the case of natural gas, the free market is not what is governing the energy source used. In northern California, industries have already been told by the local gas company that they cannot have more gas after a certain period of time; they must burn oil or coal. One reason for this approach to allocation is that it is easier for large users to switch to oil. Another may be that there are fewer votes in industry than there are among all the millions of homeowners who use gas. And since there is not enough to go around, the gas company is going to offend the least politically significant part.

I suggest that this process is likely to continue, and as the fossil fuel energy sources become less available, we will move more to an allocation society, governed in the short term largely by the political clout of those people receiving it, mainly homeowners—the most numerous votes.

One thing that would mean is that those company cost analyses from the utility point of view won't really apply, because if you cannot get an essential resource, its hypothetical cost is irrelevant. What really counts is whether a company, city, or other institution that needs to increase its energy consumption has the opportunity to go out and pay with capital for its own *in situ* production capability of, say, electricity from sunlight. If the total cost of that investment is still a relatively small fraction of the total new plant investment, it may be well worth doing.

So, in addition to the need to consider total social cost, we probably will be in a fuel allocation mode as a country. And the outcome will be that seemingly "uneconomic" energy sources such as solar, which could be acquired independently of rationed fuels, may become very desirable in some cases.

TENDENCY TOWARD REGIONALIZATION

In my view, the third part of the argument for solar is that there is a strong tendency toward regionalization going on in the country—and, for that matter, in the world. Quebec wants to secede from Canada. The San Fernando Valley wants to secede from Los Angeles County. There's always a balance between pressures to bring groups together and pressures to pull them apart. I think the repulsive forces seem to be gaining strength, at least in the Western world, which has many implications for energy. This is because the kinds of energy sources we are discussing are the ones that are globally, or at least nationally, integrated. Coal is mined in one place. It is transported to a place very far away to be burned in a very large power plant. The resulting electricity is then carried long distances over transmission lines. Right now that is not much of a problem except when a coal miners' strike serves to remind us temporarily of the interconnectedness. We have a rather strongly integrated society, but the debate on whether or not the Alaskan oil terminal should be here in southern California has interesting overtones. We don't benefit locally much from having that terminal. We have enough local oil that we don't need the Alaskan oil. Should we be the polluted port for billions of barrels of Alaskan oil to flow to our neighbors and fellow citizens elsewhere in the country? If pollution or other effects are sufficiently significant, a serious political issue emerges. There are generally similar arguments in many other parts of the country.

We are moving toward a society in which there will be real shortages of energy resources. And as we do, we must prepare for rather different approaches regionally. I think southern California and Arizona and some other states will find solar energy a particularly attractive option. However, some other parts of the country that are poor in naturally occurring energy sources and also low in available solar energy are in for a tough time. There is already a tension developing between the frost belt and the sun belt.

But that is just the tip of the iceberg. If we have the kind of energy shortage that is forecast (and seems likely to me and to many others), we may be in for a political period of very great regional tensions and differences. That fact will change the economics and the decision-making. And those areas that have local resources like solar will tend to use them.

OTHER BARRIERS TO INTRODUCTION OF SOLAR ENERGY

There are some other barriers to utilization of solar energy, and I think it is important to understand them. Some can be modified, but others are pretty persistent and deep. One genuine barrier is the investment that has already been made in pipelines, electrical transmission systems, and large-scale power plants. Money that is spent is spent. It becomes an existing resource. If we go another twenty or thirty years along the direction of ever-increasing generation of electricity from fossil fuels, we may be in an irreversible posture. There may be a point of no return when the capital outlays required to introduce a really different energy technology like solar-electric simply exceed what the then more brittle economy can muster. We certainly aren't there yet, but it is difficult to set time scales. In any case, previous investment dominates the future, and there will come a time when the U.S. probably will lose the ability to loop back in and go, for example, to a solar-based economy.

The second barrier to the use of solar energy is that it cannot come into play on a large scale until the cost of energy, whether it is in the form of gas, fuel oil, coal, or electricity, is at its real replacement cost. If a new war breaks out in the Middle East and really shuts off the Arabs' oil to the U.S., the national imperative would require a much more realistic fuel pricing policy regardless of income redistribution arguments. That unfortunate situation, nevertheless, would provide real economic incentive for the development and utilization of solar technology. If a disruption to the supply of imported oil doesn't happen (and I surely hope it doesn't because of war), but we do continue relentlessly to import more and more oil, the eventual economic effects will be so serious that we really may not have the capability to recover and to play the dominant role in

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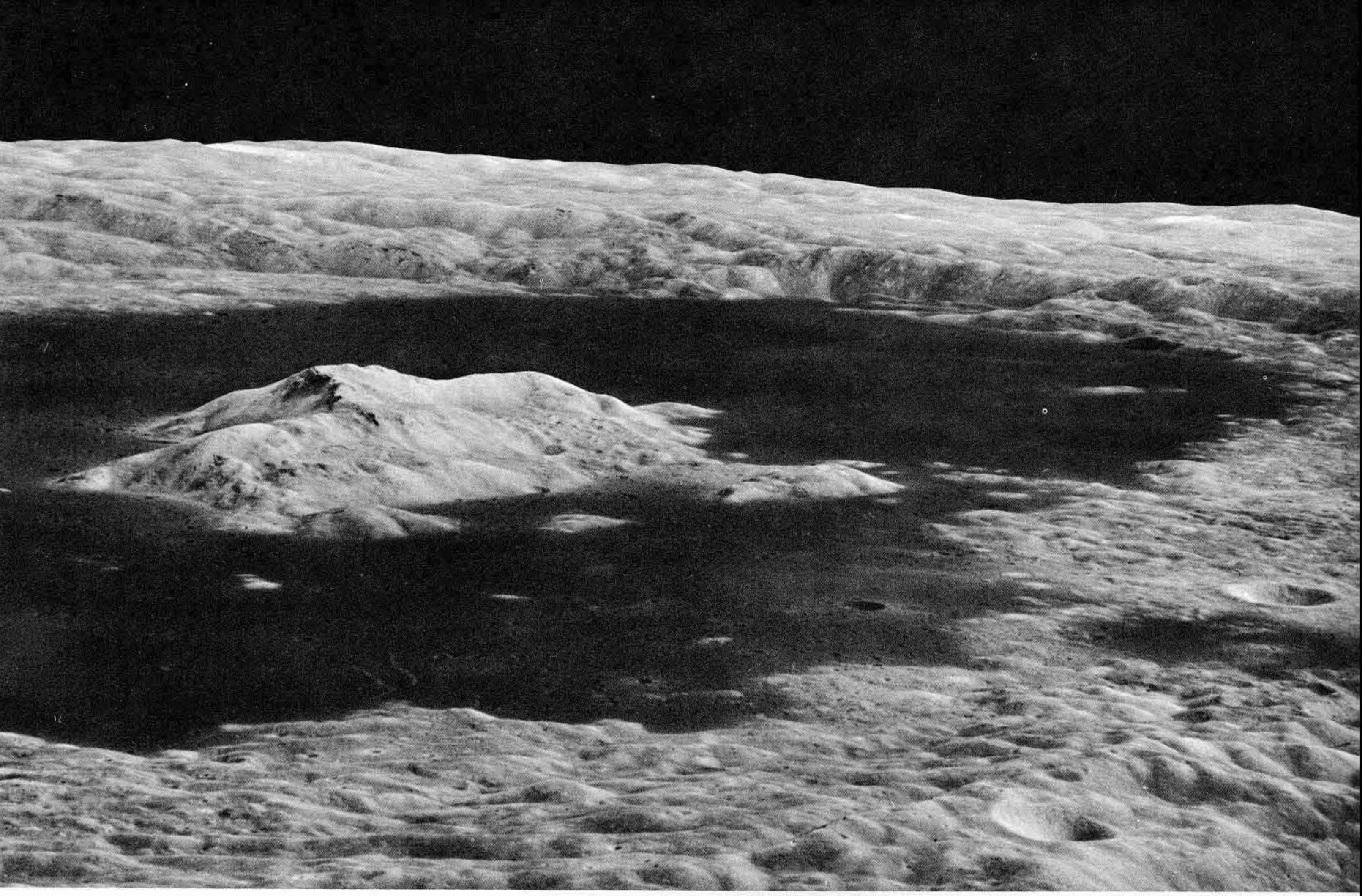


Seen relatively close up by the Apollo 15 Command Module, the 150-mile-wide crater Tsiolkovsky looks like a frozen lake with a high white peak rising from the center. The floor of the crater is of dark mare material, and it is one of the few scattered dark areas on the far side of the moon. The front side is nearly half covered with mare material.

The Moon and Beyond

by BEVAN M. FRENCH, MS '60

No longer just our satellite, the moon has become a base and a proving ground, no longer a destination but a way station on the road of continuing exploration

From *The Moon Book,* by Bevan M. French. Copyright © Bevan M. French, 1977. Reprinted by arrangement with Penguin Books.

In the centuries before the Apollo Program, we watched the moon as we might watch a stranger passing to and fro outside our house. Now we have gone outside to meet the stranger. The moon has become an acquaintance, and she has now revealed to us much of her own personal history.

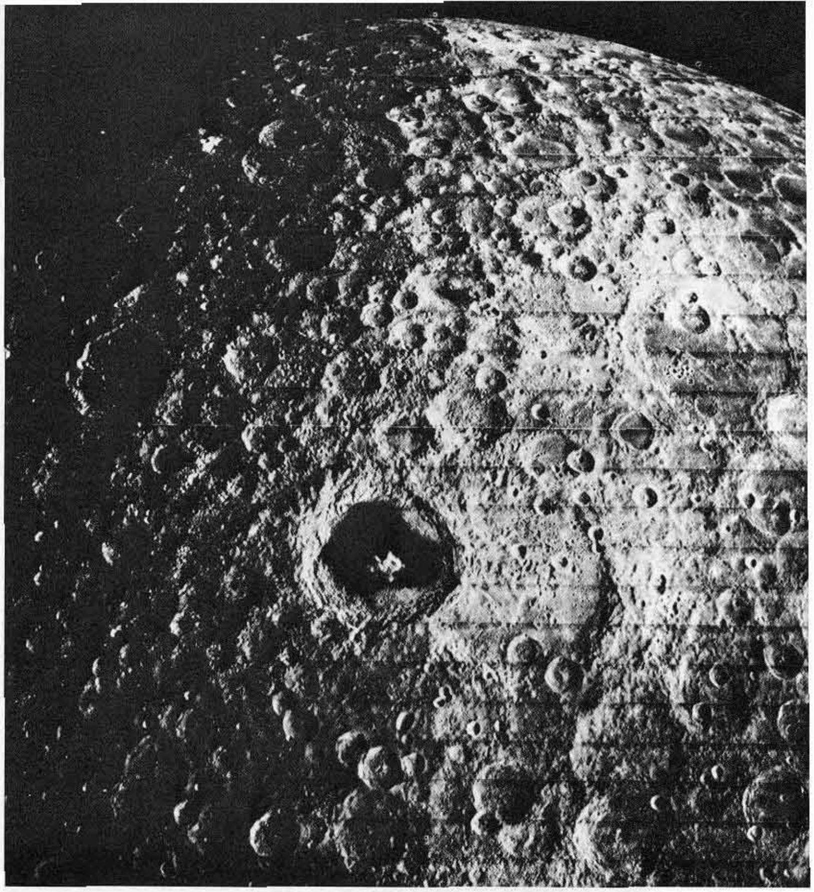
The illumination of the moon's past is probably the greatest scientific triumph of the Apollo Program, for we now have the record of another world to compare with the history of our own planet.

Despite the flood of chemical and historical information obtained by the Apollo Program, we still do not have a single, universally accepted theory for the origin of the moon. Because scientific theories always die hard, the three pre-Apollo theories (double planet, fission, and capture) have all survived the Apollo results, though often with considerable modifications.

A completely successful theory of lunar origin must explain the evidence that the moon has been a separate and unique body since its formation. It also must account for significant differences in the chemistries of the earth and the moon. This chemical disparity is the major stumbling block of the "double planet" theory, which argues that the earth and moon were both formed together in the collapsing dust cloud that became the solar system. It is hard to believe that such major chemical differences could have been produced in two bodies that formed so close together. Consequently, most current explanations for the origin of the moon combine modifications of the other two traditional theories, fission and capture.

But the original version of the fission theory—that the moon spun off as a single body from a rapidly rotating earth—has also been undercut by the Apollo data. The chemical differences between the earth and moon, especially the absence of volatiles in the moon, are so profound that it is hard to argue that the earth and moon ever were part of the same body.

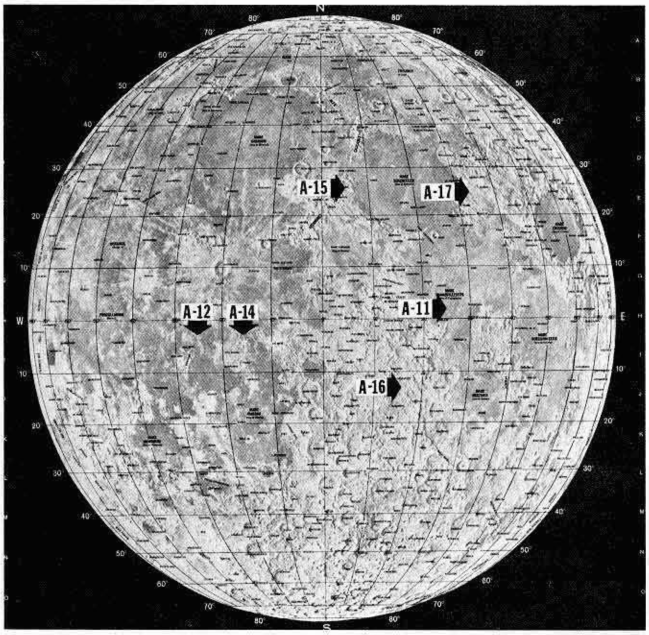
A newer variation of the fission theory suggests that the moon was built up gradually from a heated atmosphere that was thrown off a hot, rapidly spinning primordial earth. During its formation, the earth was heated up by collisions with small bodies until the temperature in its outer layers was over 2,000°C. At such a high temperature, both volatile materials and some less volatile elements like silicon, aluminum, and magnesium boiled off the primitive earth into a dense atmosphere around it. As this atmosphere cooled, the less volatile elements condensed into small rocky particles which were spun into orbit around the earth and then assembled to become the moon. The moon thus developed by separating from the earth atom by atom instead of by separation as a single mass. Since it holds that the moon formed from material whose volatile elements were removed by the intense heating, this theory does account for the different chemical compositions of the earth and moon; but, like the original fission theory, it still has a number of problems.



Photographed from an altitude of 900 miles by Lunar Orbiter III, Tsiolkovsky looks less like a frozen lake than a black eye in the relatively light-colored "face" of the back side of the moon. The crater was named after a Russian pioneer in rocketry.

Apollo's confirmation of the chemical differences between the earth and moon has led still other scientists to argue that the moon formed somewhere else in the solar dust cloud and was then "captured" by the earth. However there is some disagreement as to *where* in the solar system the moon might have formed. The loss of volatile elements indicates a high temperature of formation, which prompts some scientists to place the origin of the moon near the center of the solar system, inside the present orbit of Mercury. But if it had originated there, it would have developed an enrichment in iron, as the dense planet Mercury apparently did. Unfortunately for this argument, the moon has a relatively low iron content. Another snag in the capture theory is that the captured body has to be slowed down in order to go into orbit around a planet like the earth. A possible explanation is that the moon was slowed down by crashing into a swarm of smaller bodies which circled the earth at that time.

The Moon and Beyond



Like footprints, the locations of the six Apollo lunar landings mark the areas men have actually studied on the surface of the moon. The Apollo program has made man a space traveler, and space a permanent part of his environment.

All of these theories explain some of the data about the moon, and all of them run into difficulties trying to explain all of it; none of them can be conclusively proven or disproven. We will probably never understand the origin of the moon until we make progress in understanding the formation of the solar system itself. We have a great deal more to learn about the actual chemical processes that went on in the original dust cloud. We also need to know more about the mechanical processes which caused small particles to assemble into larger bodies and then brought these bodies together into moons and planets. When we understand these mechanisms better, we may be able to put more precise boundaries on where the moon actually originated. If it is proven that the moon originated inside the orbit of Mercury, then some kind of capture process must have occurred, no matter how unlikely it may seem. On the other hand, if new theories manage to explain how chemically different bodies could form close together, then the "double planet" origin may be correct after all.

New questions are constantly arising to complicate any single explanation of the solar system. If the formation of large moons was a normal phenomenon when our solar system formed, where are the large moons that we would expect to circle Mercury, Venus, and Mars? It could be that tidal forces on the sun have destroyed any original moons of Mercury and Venus. However, this explanation will not work for Mars, which has only two tiny captured asteroids instead of a full-fledged moon, because it is farther from the sun than the earth.

Another important post-Apollo question is whether the moon is chemically unique. Six large moons, about the same size as ours, circle the giant planets of our solar system—four around Jupiter, one around Saturn, and one around Neptune. We do not know yet whether these other moons share the high-temperature history and other chemical peculiarities of our own moon, or whether they are mostly condensed ice like the planets they accompany. An unmanned space mission to Jupiter's moons could answer this question.

THE MOON AND THE EARTH

What we have learned about the moon has also revamped our thinking about the earth. Although the earth and moon have different chemical compositions and different histories, the moon is still an important model of what the primitive earth may have been like. The moon clearly records a primordial melting and widespread chemical separation that produced a layered internal structure almost immediately after it had formed. It is likely that the present internal structure of the earth, including its iron core, also developed very early in its history, perhaps as a result of the accretion process that formed it.

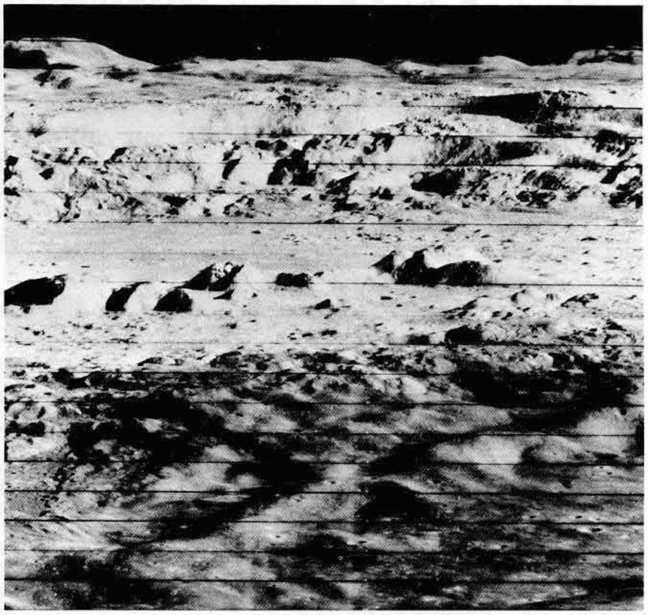
The intense early bombardment recorded by the moon more than 4 billion years ago may be a general characteristic of the solar system too. If a similar intense bombardment struck the earth at this time, it would help explain why no terrestrial rocks older than 4 billion years have been found.

The discovery of ancient rocks on the moon has also generated a new enthusiasm for probing the ancient history of our own planet. Some of this excitement derives from the discovery of rocks about 3.8 billion years old in Greenland. These unusually old terrestrial rocks were found at about the same time that the Apollo 11 mission was collecting lavas of the same age from Mare Tranquillitatis. Moreover, the surprising discovery that the lunar highlands are composed of plagioclase-rich rocks such as anorthosites and gabbros promptly spurred a renewed interest in a group of similar terrestrial rocks which occur only in minor amounts in geologically old regions. The origin of these terrestrial anorthosites is an old unresolved geological problem. Comparative studies of terrestrial and lunar anorthosites may help explain the origin of both types of rocks as well as explaining why a rock that is a minor curiosity on earth is one of the fundamental building blocks of the moon.

The earth and moon provide two contrasting examples of how differently planets can develop, and in their contrast we can see some of the factors that control the evolution of planets. Size is important. A large planet can hold volatile materials like water, and it can also retain more internal heat to produce continuous geological changes. Chemical composition is also important; a planet without water, no matter how large, lacks the one substance that is essential for the only kind of life we know. The presence or absence of radioactive elements determines whether a planet will be hot or cold during its lifetime, and the amount of iron in a planet determines whether it can ever develop a strong magnetic field. The first two bodies we have explored, the earth and its moon, show two different lines of development. Although we think that the planets all formed in the same general way, it is almost certain that we will find further different planetary histories as we explore the solar system.

AND THE LANDS BEYOND

The planets have suddenly become familiar too, for the manned exploration of the moon has gone hand in hand with the unmanned exploration of the solar system. In the five years between 1968 and 1973, scientists launched 17 heavily instrumented spacecraft to investigate every one of the five planets known to ancient astronomers. Mariner 9 went into orbit around Mars in November, 1971, circling the planet like a tiny third moon and radioing back to earth over 7,000 pictures of craters, volcanoes, canyons, and sand dunes on the Martian surface. Two years later, in December, 1973, Pioneer 10 passed safely through the Asteroid Belt, carried its instruments in a sharp turn around the giant planet Jupiter, and then sped away to become the first manmade object to leave the solar system. A sister spacecraft, Pioneer 11, made the same trip successfully a year later, swinging around Jupiter in December, 1974, and then heading outward on a path that will bring its instruments and cameras close to the ringed planet Saturn in September, 1979.



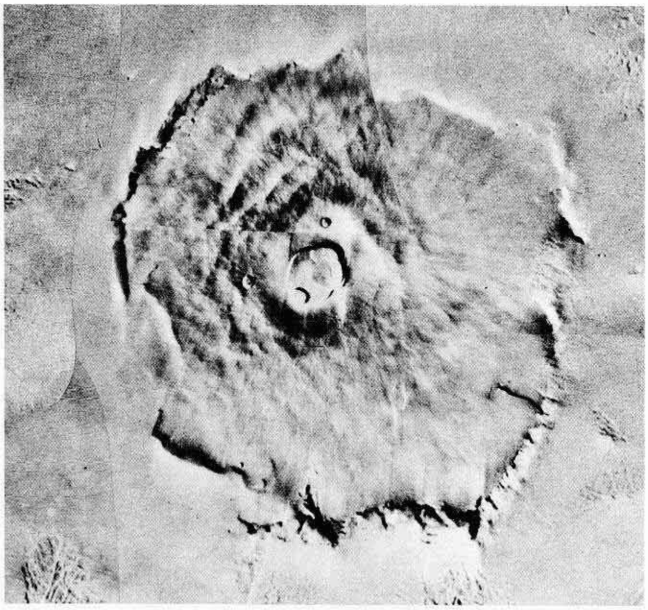
An Orbiter's-eye view of the crater Copernicus, the huge feature that dominates the upper left quadrant of the moon as seen from the earth. Copernicus is 56 miles wide and more than 2 miles deep—twice the distance from the top to the bottom of the Grand Canyon.

Mariner 10 was launched in the other direction, inward toward the sun. It passed close to Venus in February, 1974, and then settled into an orbit around the sun so well planned that the spacecraft has already been able to make three close approaches to the planet Mercury, taking pictures of that planet that are as good as our best views of the moon through earthbound telescopes.

We can now apply the lessons from the moon to other planets. We have learned, for example, that the early period of intense bombardment and cratering observed on the moon seems also to have been general throughout at least the inner part of the solar system. Mercury has revealed a battered surface that is virtually identical to the lunar highlands. The surface of Venus is shrouded in clouds, but earth-based radar, probing through its atmosphere, has detected a number of large circular depressions that are almost certainly craters. Mars exhibits two kinds of terrain. Half its surface is heavily cratered, while the other half is covered with younger features that seem to be volcanic lavas, wind-blown dust, and possible river channels.

Furthermore, the processes of chemical separation, melting, and volcanism also seem to have occurred on the other planets. Mercury has a detectable magnetic field, indicating the existence of an iron core. Photographs of the surface show units that resemble volcanic

The Moon and Beyond



Olympus Mons may be the largest volcanic mountain in the solar system. This giant Martian peak, which was photographed by Mariner 9 in January 1972, is 310 miles in diameter and rises about 15 miles above the surrounding plain—three times the height of Mt. Everest.

deposits. However, the moon has taught us to be cautious about interpreting photographs too quickly. There was a time before the Apollo 16 landing when most scientists thought that the Cayley Formation was volcanic too, and it turned out to be composed of impact-produced breccias.

The occurrence of chemical separation on Venus has been demonstrated only by a single analysis of the surface made by a Russian lander, Venera 8, in July, 1972. The lander survived for nearly an hour on the surface and sent back an analysis resembling the composition of granite, a rock that requires considerable chemical processing to produce, at least on earth.

Mars provides unquestionable evidence of chemical evolution and volcanism. The lightly cratered half of the planet contains numerous structures that are undoubtedly volcanoes. They resemble the volcanic peaks of the Hawaiian Islands, but on a much greater scale. Mars' largest volcano, Olympus Mons, is 600 kilometers in diameter—about the size of the State of Nebraska—and rises about 25 kilometers above the surface of the planet.

Not only have we discovered that the moon is not a primordial object, but our exploration of the solar system has already shown that none of the small planets is likely to be an unaltered sample of the solar system. Perhaps we will have to search for original solar system material in Jupiter, in its icy moons, or in the bodies of comets that occasionally pass by us. We may even discover that the evolution of the solar system has so altered all the matter in it that there is nothing left of the original ingredients.

Our view of the distant universe also changed radically during the decade we spent exploring the moon. The same technology that carried man to the moon also invented new optical and radio telescopes to study the far corners of the universe from the surface of the earth. From new observations, and from unexpected discoveries of strange objects like quasars and pulsars, astronomers have recently been able to put boundaries on the size and age of the known universe. The universe seems to have an edge, or a boundary, at the unimaginable distance of about 15 billion lightyears away from us. Ages calculated for the universe fall in the range of 10 to 15 billion years; it is somewhat surprising that the universe seems to be only three or four times as old as the earth.

ROBOT ASTRONAUTS OF THE FUTURE

The next machine to go to the moon will probably be a Lunar Polar Orbiter, a spacecraft designed to observe and analyze the whole surface of the moon from lunar orbit. It would be placed so that its orbit passes over the north and south poles of the moon instead of being limited to the region around the lunar equator analyzed by the Apollo missions.

The Lunar Polar Orbiter will make it possible to extend the scientific measurements that so far have been made over only about 20 percent of the moon's surface. In a polar orbit around the moon, the spacecraft would eventually pass over its entire surface, because the moon rotates on its axis once every month while the Orbiter is passing over it.

Lunar samples have already been obtained by mechanical means. On September 20, 1970, an unmanned Russian spacecraft called Luna 16 landed in Mare Fecunditatis. Using a hollow drill, the spacecraft collected a 100-gram (3½-ounce) sample of lunar soil and returned it to earth. In an important step in international cooperation in space, some of the Luna 16 material was given to American scientists in exchange for Apollo 11 and 12 soil samples.

The instruments available for analysis of lunar samples are so sensitive and so precise that the small amount of Luna 16 material obtained from the Russians (about 3 grams—the weight of ten aspirin tablets) yielded an impressive amount of information. Scientists discovered that the surface of Mare Fecunditatis was covered by titanium-poor basalt lavas about 3.4 billion years old. The lavas were similar to, but slightly older than, the rocks returned from Oceanus Procellarum (Apollo 12). Even at a considerable distance from the Apollo landing sites, the lavas still seem to be about 3½ billion years old. The Luna 16 soil had also been heavily exposed to cosmic and solar atomic particles while on the moon, but it is hard to interpret the effects because there is so little material available for study.

Seventeen months later, on February 21, 1971, Luna 20 landed in an area of the lunar highlands between Mare Fecunditatis and Mare Crisium. Samples of this soil, also exchanged with American scientists, proved to be made up of crushed plagioclase-rich rocks very similar to the breccias returned by the Apollo 16 mission from the highlands near Descartes.

The Russians are still continuing their sampling of the moon by robot spacecraft. On August 18, 1976, Luna 24 landed safely in Mare Crisium, a small circular mare on the eastern edge of the moon. The spacecraft drilled about 2 meters deep into the lunar soil, then returned safely with a core section of the soil layer that provides a unique sample of the nature and history of an unknown part of the moon.

Existing spacecraft or their more complex descendants, can easily return similar samples from the moon. Our analytical instruments make it possible to obtain a great deal of scientific information from a tiny sample, and our experience with the larger samples obtained by the Apollo missions provides a necessary check on our interpretations.*

In future missions, it will be possible to combine unmanned sample collection with a roving vehicle that moves over the lunar surface. So far, the Russians have the only experience with unmanned lunar roving vehicles. Some of their Luna missions, instead of returning samples, landed a wheeled vehicle called *Lunokhod* (roughly, "moon-walker"). Controlled from earth, the vehicle traveled over the lunar surface, transmitting back TV pictures and data about the physical and chemical nature of the surface.

Future roving vehicles may travel for hundreds of kilometers, measuring the chemistry, gravity, and magnetic properties of the surface as they go. Even more complex rovers, equipped with TV cameras and guided from earth, will be able to examine the local geology and collect samples. At the end of the trip, the cargo would be transferred to a small spacecraft for return to earth.

Where should we send these machines on future missions? Landings on the near side of the moon are easiest to control because the machines are always in sight of the earth and can receive instructions continuously. The search for young volcanic rocks in the maria is one of the most important things that could be done on the near side of the moon, because it would help establish new limits on the thermal history of the moon. Studies of the number and distribution of craters on the maria suggest that young volcanic rocks may be found in parts of Mare Imbrium and Oceanus Procellarum; ages as young as 2.5 to 1.7 billion years have been estimated for these rocks. If these ages could be verified from returned samples, the whole history of the moon would have to be revised. The Marius Hills, which have already been identified as some of the youngest volcanic features on the moon, are an obvious landing site for such a mission.

Another unmanned mission could try to determine the origin of lunar transient phenomena by landing where they have been most often seen, in the craters Aristarchus, Alphonsus, or Plato. In addition to collecting samples of possible recent volcanic rocks, the spacecraft could leave instruments behind to await the next "eruption"—a seismometer to detect moonquakes, a heat flow experiment, and an atmosphere detector to sample diffusing gases.

Much remains to be done on the near side of the moon, but the entire far side of the moon is practically unexplored, and scientists are eager to send instruments there and to obtain samples. The curious magnetic anomaly near the crater Van de Graaff is an obvious site to place an instrument package, and the mare-filled

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*There is a continuing debate over whether the scientific results from the Apollo Program could have been obtained at much less cost with unmanned samplers similar to the Luna 16 and Luna 20 spacecraft. In many cases the answer is no. The unmanned samplers returned only a small amount of soil and no large rocks; the one formation age determined for the Luna 16 material was made possible by an incredibly painstaking analytical effort on a rock chip that weighed 0.062 gram. The larger samples returned by the Apollo missions were essential to learning about formation and exposure ages, highland breccias, microcraters, lunar magnetism, the nature of solar wind, cosmic ray particles, and the layering and history of the lunar soil. The formation ages measured on large lunar rocks were especially important; without these ages, we might have concluded that the model age of the lunar soil, about 4.6 billion years, was actually the age of the mare lavas. Without the large rocks from Apollo, on which the true formation ages could be determined, our whole view of lunar history might have gotten off to a very false start, and we might never have learned that the moon had been an active evolving planet for a billion and a half years.

crater Tsiolkovsky could provide samples of both the highland crust and of the dark mare material that for some reason is so scarce on the far side of the moon.

Landing spacecraft on the far side of the moon is a difficult problem. On the far side of the moon, the spacecraft is out of radio communication and cannot be controlled directly from earth. One solution is to build a complex spacecraft that can be programmed in advance to land and perform its tasks without any contact with earth. However, a simpler and less expensive solution is to put a relay satellite in orbit over the far side of the moon, where it can "see" both earth and the lunar far side at the same time. Fortunately, nature has done most of the necessary work for us. Some distance beyond the moon, there is a point where the gravity fields of the earth and moon combine in such a way that a satellite placed there will always stay there, remaining on the far side of the moon as the moon orbits.

With such a relay satellite in orbit, nearly continuous communication between the earth and instruments on the lunar far side would be possible, and more ambitious explorations can be planned. The most important scientific step will probably be the landing of a group of seismometers to explore the interior of the moon beneath the highlands. More complex instrument packages could measure chemical and magnetic properties as well.

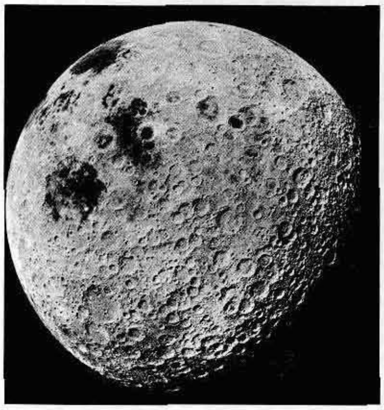
It may soon also be possible to put instruments on the far side to study things beyond the moon. The far side of the moon is an excellent place to do astronomy; it is entirely airless, utterly dark for half of the time, and shielded behind the entire mass of the moon from the lights and radio noises that make both optical and radio astronomy difficult on the earth. Small automatic telescopes placed there could make observations that are impossible for instruments on earth. They could observe the ultraviolet and infrared light of the stars; and seek new sources of radio waves, X-rays, and gamma rays in the sky; and possibly even find new examples of such puzzling objects as quasars, pulsars, and black holes.

The United States may not have to undertake these explorations alone. The new feasibility of international cooperation in exploring the moon is an important result of the Apollo Program. There is the precedent of Antarctica, where many nations, including the United States and Russia, have cooperated for over a decade in the scientific exploration of a continent about one-third the area of the moon itself. The more recent examples of the lunar sample exchanges and the joint Apollo-Soyuz mission are also encouraging indicators of future cooperation in space between the United States and Russia. It is possible now to plan a joint mission in which a Russian Luna spacecraft would descend to sample the crater Tsiolkovsky guided by an American relay satellite fixed above the far side of the moon. Geologists could easily plan voyages for a Russian Lunokhod that would collect samples along a trail a hundred kilometers long and then transfer them to an American robot spacecraft for return to earth. Or it could be an American rover and a Russian spacecraft. Neither the hazards of the moon nor the state of our technology is the factor determining whether such cooperative exploration takes place. We now know that such joint missions can be done if the governments and individuals involved decide that they should be done.

Another great gain from the Apollo Program is confidence. Already the exploration of the moon has changed from a great unknown challenge to a matter of relatively familiar engineering. What will determine the future exploration of the moon is no longer our ignorance and uncertainty about the universe, but the resources of desire, talent, and money that we ourselves provide.

In this post-Apollo period, the moon has become in some ways as familiar as the earth, and the other planets are becoming as familiar as the moon was a decade ago. No longer just our satellite, the moon has become a base and a proving ground, no longer a destination but a way station on the road of continuing exploration.

Despite our partial domestication of the moon it would be foolish to think that we have learned everything important or interesting about it. The Apollo Program has let us, as Newton put it, pick a few pebbles from the edge of the boundless ocean, but there is still much to be learned from studying the beach while we make plans to venture out onto the ocean itself. □



A farewell look at the far side of the moon was taken by the Apollo 16 astronauts on the way home to earth.

The Future of Japan

Continuity and Discontinuity in Social Change

by MICHIO NAGAI

The last time I was at Caltech was on December 4, 1970, and I remember the date so well because only a week earlier a friend of mine, Yukio Mishima, the foremost Japanese writer, committed suicide. He committed suicide for complex reasons, one of them being that he was deeply concerned about the type of culture that Japan was getting into—the rapidly changing contemporary culture with variable residue of traditional classical values that he cherished so much.

The theme of the conference I attended here in 1970 was Hopes and Fears—The Future of Technology, and Professor Carroll Wilson of MIT gave a good talk about five important factors that should be considered—namely, environment, energy, industrialization, population, and food.

More than six years have passed since my last appearance here, and I came back because I was out of office in the Ministry of Education, to discuss the subject of continuities and discontinuities.

In 1970, when I listened to Professor Wilson talking about the future of mankind being in danger, I felt that people seemed to be talking about the future as though the future would be entirely new. To my mind this is rather a one-sided view of history. There are many things that move on from the past to the future, so it would be better if we considered discontinuity as well as continuity.

I say this probably because I come from the city of Tokyo, where I was born in the spring of 1923. In the autumn of that year there was a great earthquake in Tokyo, and Tokyo became simply a flat land. A large number of people died. Then I grew up in Tokyo and people began to rebuild houses. We got into the Japan-China War. Later we attacked Pearl Harbor, which started a second World War that ended with the use of nuclear weapons in Hiroshima. By the time Hiroshima became flat land, nearly all cities in Japan had also become flat land.

So I remember very clearly the postwar experience of living on flat land for some years. I am only 54 years old, yet in my lifetime there have been many changes in the city of Tokyo and in the country of Japan. I realize that in the city of Los Angeles there have not been air raids or very great earthquakes or any bombing by nuclear weapons. On the whole, in spite of such things as the Great Depression, and the American engagement in WW II and in the following war in Vietnam, the city of Los Angeles remained, I think, nearly the same except with some great expansion to suburban areas and the like. But, to me, these changes—the rise and fall of a great city, and the rise and fall of a great nation—are a natural experience.

In spite of the fact that Japan is now said to be a country of great economic power, I don't expect this to continue forever. I am psychologically prepared for Japan's economic downfall.

The Future of Japan

These changes I saw in Japan did take place not only there but in most of the countries of the world. In fact, the United States has been rather an exceptional case in the 20th century. The 20th century could be characterized as a century of wars and revolutions, so it would not be at all surprising if from now on there were to be many other upheavals and terrorist activities and possibly small-scale wars, if not nuclear war of the kind we experienced once.

Why do we have all these changes? This is an important question if we are to speculate and think about 80 years ahead. Of course, it takes time to analyze why wars, revolutions, depressions, and upheavals occur. In the 20th century there were the Russian Revolution and the Chinese Revolution, and together they produced the two gigantic socialist states we have in the world today. Before that, of course, we had the American Revolution for independence and the French Revolution.

I don't have the time or capability to analyze these things. I'll simply say that there is something inherently difficult in what is called industrial democracies. To my mind an industrial democracy conceptually contains elements of difficulties, if not conflicts and contradictions. Industrial democracies, I think, developed thanks to two types of revolutions. One was the Industrial Revolution; the other, revolutions of many kinds that could all be called social revolutions. The Industrial Revolution aimed at many things, among which some important values stand out, such as efficiency, so-called better living standards, more quantitative achievements in human life, and improvement of convenience. All these things were considered to be the important values of the Industrial Revolution by Eric Ashby, who wrote about them so beautifully in his book on the scientific revolution and the university in the United Kingdom. In addition, since the beginning of the Industrial Revolution, *progress* has become a key word that can quiet down any discussion. Once people said, "This is progress," it was supposed to be good under all circumstances.

To achieve those values, industrialization came to design certain types of organizations that were called bureaucracies. In such bureaucracies there are many important principles of organization, such as division of labor. Therefore there's bound to be specialization which ends up as overspecialization. In a bureaucratic organization, there is bound to be coordination or overspecialization or a division of labor. This results in the building up of hierarchies of organization, so that on the top of the organization there's a president who is supposed to overlook everything, but who knows very little about the special activities in specialized fields of his big organization. In this organization, principles of equality, achievement, and efficiency are all cherished, but the important thing is that there is hierarchy as well as specialization. Therefore, when you say Industrial Revolution and bureaucracy, there seems to be some consistency in the values and principles of processes and organizations.

But other revolutions—the American Revolution, the French Revolution, and perhaps also the Meiji restoration of Japan in the late 19th century—aimed at a different thing. What they aimed at was to bring about equality to a great degree. Of course it was much lower than the degree that we see today, but it was a great achievement in those days, in the eyes of a French traveler to the United States like Tocqueville, for Americans to be living on an equal basis.

Liberty was also quite important. Another important element of the changing social life could be summarized in the idea of Jeffersonian democracy. People all get together in a small square of the town and discuss things and do and say whatever they wish to. So this would be called agrarian democracy—which is different from industrial democracy. When you compare these two types of organizations and values, you can easily find that there are many differences, if not sharp contradictions. Representative democracy is far more agreeable to the development of agrarian democracy in a small township, while representation of people for a big nation like the USA would be pretty difficult. Jeffersonian democracy by this time has been modified to a great degree, and sometimes scholars complain that politicians are thinking only of local interests and that they are not interested in the affairs of state.

But the kinds of things we have all talked about are that we must be concerned about the future of industrialization, and an industrialized society is such a complex organization, and at the same time so sensitive, that any mistake or any change that could take place in this complex organization could bring about total destruction. That is quite correct and plausible.

I, as a Minister of Education, was responsible for 25 million Japanese from kindergarten up to graduate school. As a chief bureaucrat in Japan I had many ideas that were very hard to enforce, even if I passed laws in the Diet, because there were all sorts of voices against me. That is related to representative democracy, or agrarian democracy. In some localities, people said that Minister Nagai had the erroneous idea of trying to put too much emphasis on mathematics, although what is necessary in a given sector in Japan is a closer study of agrarian development. These voices were all over Japan while I was in office. Therefore, it is not at all inconceivable when you live in the days of industrial democracy, that all these inconsistencies and contradictions sometime could rise to the surface and explode to the degree of upheaval.

That has happened in many places. In the United States, I understand there are all kinds of racial conflicts, and responsible people in Washington and in the Department of State try to mix people of different races. Yet those policies on the whole never come to real satisfaction for every race. Through representative democracy, each group voices opposition to these policies that are being thought about by intellectuals and sophisticated scholars.

These are the things that have happened in our so-called developed nations in the 20th century. Even in a country like the United Kingdom, which is a most sophisticated and experienced and gentle nation, there are clashes between two Irish classes constantly. This again is not at all surprising when you think of the nature of industrial democracy.

When I think of the world of tomorrow, then, I think of things that could take place in Africa and also in many other parts of the world, including so-called developed nations like Japan. There were something like 40 coups d'état in the 1960s, and in many nations of Africa there is dictatorial leadership rather than representative government. I was in Australia recently. Reading a newspaper, I found that Queen Elizabeth was visiting that country. Unfortunately she was met by groups of dissenters there. In her farewell to the people of Australia she said, "It was unfortunate I met dissent in this country. However, dissent is a sign that this country still enjoys freedom . . . freedom that is gradually disappearing in many parts of the world, so sadly."

She is quite right that in these days in the world freedom is disappearing gradually. In place of representative government, we have upheavals and so forth, and dictatorships outnumber nations that belong to the free world.

These are the things one must bear in mind when thinking of the future. I realize that I'm not talking at all about energy, environment, and population, but I am the kind of person who is not at all learned in these important subjects.

Let me now come to the question of the future of Japan. What will Japan face with reference to such questions as, for example, energy. Japan of course is known as a country that depends on imported petroleum to a greater degree than almost any other country in the world. Almost 100 percent of our petroleum comes to Japan from other lands. In addition, 40 percent of our food supply comes from other nations such as the United States, Australia, and Canada. Premier Chou En-lai of China once told Japanese businessmen that Japan was not a great economic giant. "That is nonsense," he said. "Japan is a great manufacturer, that's all, because Japan is so short of resources she is importing energy and food, and she is only manufacturing things—selling Toyotas and Sonys all over the world." I think Premier Chou En-lai was quite right in characterizing Japan as a great manufacturer rather than Mr. Herman Kahn's great economic superstate.

When I look at Japan as described by Chou En-lai, of course I feel that the future of Japan is quite shaky. Once there is a petroleum crisis and once the price of petroleum rises up so much, there's bound to be inflation in Japan instantly. This took place in 1973. And when Mr. Nixon thought about not selling soybeans to Japan, the Japanese were again very much shocked and surprised by the shortage of bean-curd cake.

Those who are knowledgeable in such matters say that there is a relationship between the rise and fall of the economy of a country and the consumption of energy. This is a language of which I have very little command, but in the case of the USA and various European nations I understand that as there is a decline of GNP, there is less consumption of energy. That on the whole is true, although there should be some qualifications. In the case of Japan, in spite of the oil shock, somehow the country has been doing very well; the consumption level of energy has not fallen since the oil shock. Yes, we have suffered a great deal in our economic policies since the oil shock, due to the situation that is called stagflation—a combination of stagnation and inflation. As far as the Japanese are concerned, nobody sees any way out of this serious dilemma for us.

The Future of Japan

As a Minister of Education, and as a Cabinet member, I had to share my responsibilities with the Minister of Finance. Ministers of Finance in the last three or four years have suffered a great deal. In December 1974 the inflation rate of Japan was more than 30 percent—surprisingly high. It was only natural for the Finance Minister to try to depress and control inflation. That was what he did, successfully. By the end of 1976, the inflation rate in Japan came down to 8 percent. This was a great success, but it only invited recession in the Japanese economy—the stagnation side of it. Therefore, when one succeeds in controlling inflation, then the stagflation comes, and so the present Minister of Finance, and the Prime Minister, are saying all the time that they will buoy up the Japanese economy so that we can get out of stagflation. At present, the operating ratio of Japanese business is only 70 percent in proportion to the number of people employed, and in proportion to the amount of equipment. Therefore, I should think there would be some change in the Japanese economy this year, that probably Japan will somehow get out of the stagnant recession. At the same time we will begin to suffer inflation.

Looking at European nations, I don't find any exception where there isn't some of this curious combination of stagflation. It was true in Australia, and I'm afraid I find it true in the case of the United States. Should there be any genius like Lord Keynes, we may be able to get out of stagflation, but so far, as far as my knowledge is concerned, there doesn't seem to be anyone who has a really ready-made cure for this new disease. As a result, as the Ministers of Finance in Japan try very hard to control both, somehow inflation has come up and recession has come up, which has led gradually to the deterioration of the Japanese economy.

In addition, another aspect of the future of Japan has already been talked about in this conference: that is, the replacement of some Japanese industries by developing nations. We competed once with British Lancashire people to retain our leadership in the textile industry—as we did with the Americans in North Carolina. But now we are in the position where it is certain that the South Korean people will replace our textile industry. It is only a question of time before the Japanese textile industry will decline. If you visit Tokyo and go to a department store to buy a shirt, please be careful to look at the shirt and if it says Made in Korea, buy it, because it's cheaper and as good in quality as the ones made in Japan.

The Japanese are now quite proud of the fact that they sell good Toyotas and Datsuns and Sonys, and so on—all those things that Americans were very proud of, which they manufactured in places like Detroit and many other cities throughout the country. Now the Japanese have taken over some of those markets, but the Koreans and people in Taiwan may be gradually building better automobiles—and again it's just a question of time before nice Korean Toyotas will come to Los Angeles.

Putting all these things together and looking at the past we see the rise and fall of a nation. I feel that now Japan is just about at the peak of its prosperity and beginning to crank down. Therefore, in the years ahead, when our economy cranks down, we will suffer—though not so much from the crisis of energy, because we won't be using energy so much.

This, I'm afraid, is the kind of thing that has not been discussed much. It is as though all the developed nations were going to develop forever in the 21st century, and people are concerned about developing nations, but I'm inclined to think that the two types of revolution that took place in the late 18th and the 19th and 20th centuries have now led us to the stage where we may come to a possible revolution of a new kind. It's not that we want our living standards to become lower. If any political candidate for the office of President of the United States or as a member of Commons ever made a speech to his constituents that promised, "I shall lower our living standards," he would certainly fail in his election.

To be a politician simply would not be consistent with making that kind of speech. In Japan, too, there is no politician at all, on the right or the left, who says that, "I, if elected, shall be determined to lower the living standard of the Japanese," and I am sure there is none in Britain. Yet British living standards have become lower. It was not because people wished that living standards would become low; it was because of social changes that have taken place there. Therefore I think a similar thing could take place in the far eastern end of Asia where Japan is enjoying prosperity, and I think it may be a matter of time before Japan follows in the footsteps of Great Britain and becomes a country like "Little" Britain. Should that be the case (although I am not at all arguing that this is a path we will be moving toward in a linear way; I am talking about this as a possible path), I think we would have a new style of life in the future, enforced by circumstances.

These changes could happen in Japan. They would lead to a simpler life, and one that takes far smaller amounts of energy. At the same time there will be more development of agrarian production because those in industry will not be making so much money, which would mean that people in agrarian areas will begin to think that their way is as profitable as those in industry.

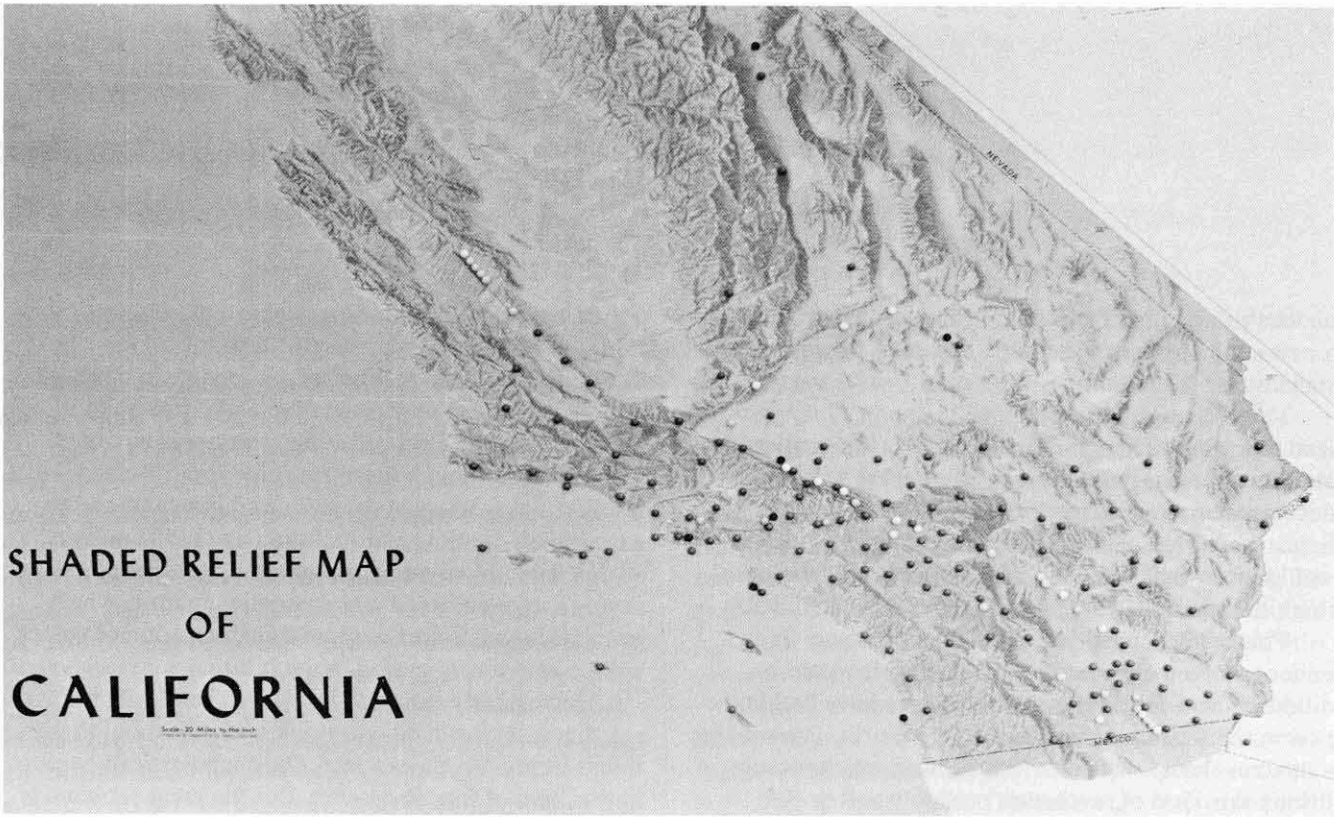
This is my conception of what could come about under enforced circumstantial changes. It would be different from the kind of revolution we have had in the past in the western hemisphere of the world. It would be a new revolution with new values. And, on the whole, I think this kind of revolution probably will be desirable. Although I think a decent life will be quite important for people, I am not at all sure we really have to level-up our living standard to the degree that we could have a scotch and soda every night or enjoy a luxurious hotel life anywhere we go. I am not sure that would be a decent, satisfactory life. That has been the standard for this century, but it may belong to the past.

Now, should this happen, I think developing nations will find a new model of civilization and they will suffer far less in comparison to today. As a Japanese, after the defeat I came to the United States as one of the first Japanese students to study in this country. At the time I came here it was July 1949, and Japan was a very flat island. People were hungry and life was difficult. I came here to find so much and so many things—an abundance of things. I was taken to a supermarket and was met by the manager, when I was at the age of about 23, and I was surprised to see the cans stacked along the walls clear up to the ceiling. I was convinced these were all empty cans. I thought this was the famous American commercialism, to show people that they had so many cans, so that people would then be attracted to the supermarket and would buy things. So I said, "Are these all empty?" The manager could not understand what I was asking. Also my English was bad. So I asked many times and finally came to the answer from the manager that all these cans were *full.* I was terribly frustrated to find that in the United States there are so many cans that are full, that are not eaten every day by people. As a person coming from Japan, where the land was very flat, should I find that all those cans were empty just for commercial advertisement, I would have been far less frustrated.

Based on that small experience, and on many other things, I have great sympathy with people in the developing nations. It is better that people in developed nations come to a new revolution and come up to a new style of life. This, of course, will never be done voluntarily, although there are some sophisticated intellectuals who leave the cities and buy land and engage in half-farming and half-teaching at the university—that is a limited number of people. But what I am saying is that enforced circumstantial changes which bring about some sort of great transformation of values will be very much needed in the future.

I have nearly exhausted my topic, but lastly I must say that it is worthwhile to think and talk about these things in present-day society. Only scholars can engage in this kind of free discussion. But the great problem is how our ideas can be related to practitioners—politicians, bureaucrats, and the like. What is needed in the future is an interoccupational approach to a question of this kind. Scholars getting together and discussing endlessly will not bring about much change in society unless scholars persuade politicians, and politicians persuade voters. Using the mass media is another possibility. In my life I have been a university professor, then a journalist, then I was Minister of Education. It is important for people to be interoccupational and at the same time international. Although there is so much talk about the future, of the possible revolution, or about the future of Africa—if this is not conveyed to the Japanese, it wouldn't mean much. Nor does it mean so much as far as Africans are concerned.

Therefore I think we all must work together interoccupationally, interdisciplinarily, and internationally—and not really expect to produce any radical and sudden changes. You should not believe that intellect so easily could change the world. That has not happened much in the history of mankind. Intellectuals have written many things, but history has changed thanks to power conflicts, thanks to upheavals, thanks to some sort of circumstantial enforcement. What intellectuals *could* be doing is to be prepared for that, and not be shocked so much by it. I am saying that we've got to have all kinds of efforts to combine these international, interoccupational, and interdisciplinary approaches—meetings of all kinds, and working together. This is very important—not really to bring about changes, but to be prepared for the shock. Before some great change comes, we've got to have planned really to bring about a new society. □



Southern California network of seismographic stations is the world's largest seismic array.

50 Years At The Seismo Lab

Don L. Anderson, director of Caltech's Seismo Lab since 1967.

The world's largest seismic array got its first public exposure in December when Caltech's Seismo Lab celebrated its 50th anniversary. The first seismometers were put into operation in southern California by the Seismological Laboratory in 1926. For the next 50 years the number of seismometers slowly increased with step-function increases after the earthquakes of 1933 (Long Beach), 1952 (Kern County), and 1971 (San Fernando). Recording initially was on photographic paper; the records were mailed to the Seismological Laboratory and read individually. Locations of events were not precise for days or weeks after the event, and complete catalogs were often not available for years. There are now more than 160 stations in southern California; these are telemetered directly to a computer at the Seismological Laboratory which digitizes, detects, and stores the seismograms on magnetic tape. These are read by an analyst interacting with the computer, and complete earthquake catalogs are available the next day. Important events are located within minutes. The southern California network is now the world's largest seismic array, being about twice the size of the Large Aperture Seismic Array (LASA) in Montana. It is being used not only for the precise location of local events, but also of earthquakes occurring anywhere in the world and for precision studies of the structure of the earth's interior. Over 200,000 seismograms are now stored on digital tape for further analysis, primarily in conjunction with the new national program in earthquake prediction.

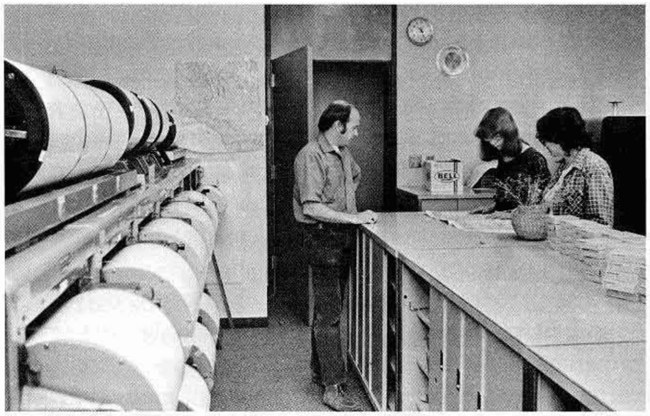
The original Seismological Laboratory in the San Rafael hills was occupied in 1927. This is the Kresge Laboratory, which is now the base for off-campus operations. The Seismological Laboratory was officially named in 1928. It was then a part of the Carnegie Institution of Washington, but people from Caltech such as Millikan and Hale were instrumental in its creation. The laboratory was run by a joint committee from Carnegie and Caltech from 1931 to 1937, at which time Beno Gutenberg was placed in charge. It gradually became an entirely Caltech operation, with Gutenberg being named Director by President Lee DuBridge in 1947. He was succeeded by Frank Press, now the President's Science Advisor, in 1957. Don Anderson became Director in 1967.

The 50th anniversary of the Lab was celebrated on December 2 and 3, 1977, when faculty, students, staff, alumni, friends, and associates gathered at Caltech for a two-day open-house-seminar. Honored guests included Imra Buwalda, the wife of the first Chairman of the Division of Geological and Planetary Sciences; Hertha Gutenberg, the wife of the first Director of the Seismological Laboratory; Professors Emeriti Charles Richter and Hewitt Dix; and Francis Lehner, retiring Group Supervisor, whose service with the Seismological Laboratory started in 1929.

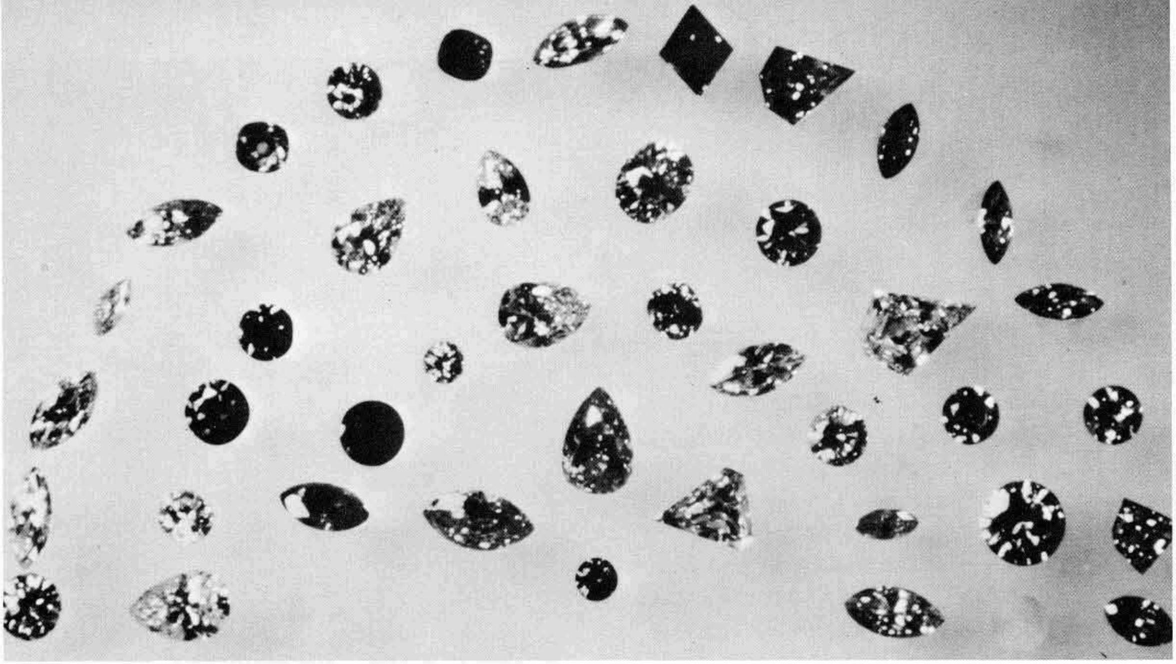
A technician measures the amplitude and arrival time of an earthquake on a microfilm display of a seismograph record.

For the occasion the laboratory was turned into a self-guided science museum with displays showing research projects on earthquakes, earth structure, earthquake prediction, field projects, Mars seismology, ultra-high pressure geophysics, and plate tectonics.

An all-day symposium covered the full range of activities at the laboratory, including real-time tectonics, ultra-high pressures, plate tectonics, the Seismic Array, and southern California crust and mantle and attenuation and creep in the mantle. Caltech is at the forefront of research in all of these areas. ☐



Reading one of the records from the imposing array of seismograph recording drums in the Seismological Laboratory.



Glitter: Gems or Gyps?

The variations of color in minerals makes the difference between a valuable gem and a worthless stone. So, naturally, there are many ingenious ways to manipulate that color. A mineralogist describes some of the pitfalls that can accompany artificially colored gemstones.

by GEORGE R. ROSSMAN

From the earliest beginning of human history, mankind has been fascinated with the rocks and minerals of this planet, both for tools and for items of beauty. For centuries people have sought minerals that have certain characteristics they consider desirable—color, clarity, hardness, and rarity, for example. A mineral with these qualities is considered to be a gem.

It is the color that makes the difference between valuable gems and worthless stones. (Imagine a brown emerald or a pale pink ruby.) As a scientist, I try to study the origin of color in minerals and its relationship to other properties such as the chemistry or the structure of atoms.

The pyroxenes, for example, which are widely abundant in southern California, commonly exist as dull brown or black minerals except for one particular variety—jade. Most jade is composed of many different minerals, but one is present in abundance, and that is jadeite. This is the mineral that constitutes the bulk of precious Asian jade.

To understand the color of jade, you must delve a little bit into its chemistry. When jade is chemically pure, it is a sodium aluminum silicate. Each one of those individual constituents is incapable of causing color in the mineral, but as we all know, color does occur in jade. Obviously, the color must be due to the presence of other chemical entities.

One of the most important "impurities" in jade is the element iron. A very small amount of iron, typically 0.5 to 2 percent, can substitute for the aluminum of the jadeite, giving rise to the familiar soft green color of one variety of jade. The color of the most precious jade is brought about by the presence of the element chromium substituting for some of the aluminum. This causes a richer, more intense apple green color.

The presence of chromium is not the only way that jade can obtain a rich color, however. Jade specimens of inferior quality may be artificially dyed to bring about a more desirable shade. How do you know, when you buy an item of jade, whether the attractive color is intrinsic to the jade itself or one that is brought about by human intervention? This is a problem we can address in the laboratory through the tools of science.

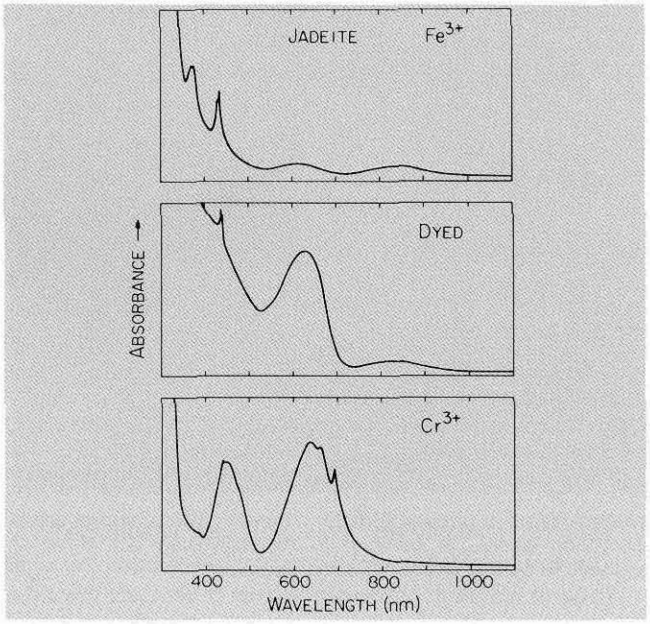
The chemicals used to dye things like jade are organic chemicals, in many respects similar to food coloring or coal tar dyes. They have certain characteristic properties, and with careful study, we can see properties in the color spectrum that allow us to determine whether or not the color is the chromium of natural precious Asian jade or whether it is simply a chemical.

We do this by quantitatively measuring the pattern of light absorption in a sample. We send a beam of light of different colors through the sample and monitor the intensity of light that is transmitted. A range of wavelengths from 400 to 700 nanometers covers the visible spectrum from violet to red. A sample of mineral that transmits light only in the 520-nanometer region will have the color green because both the red and violet are removed.

In the laboratory we extend the measurements beyond the range of visible light into the region of heat radiation, into the infrared region of about 1000 nanometers wavelength. The pattern we get consists of a series of absorption bands, and a high point on the curve means a high amount of light absorption by the sample.

When we compare a variety of samples of jade that have different coloring agents, we see differences in the patterns of light absorption. In a sample colored by the element iron, the pattern of absorption is typically weak. It consists of two broad absorption bands and then a sharp spike in the vicinity of about 400 nanometers. This contrasts sharply with a sample of jade that has been dyed, where we see a relatively strong absorption band in the area around 600 nanometers. A sample that has chromium in it shows a pattern with a sharp fine structure in the same region. Each of these patterns constitutes a diagnostic fingerprint by which to tell the origin of color in jade. It is thus simple to distinguish a dyed sample from a natural one.

Another stone that is sometimes dyed is turquoise. Turquoise is a copper-containing mineral, and the deep blue coloring of prime quality turquoise is brought about by the copper itself. But samples of a mineral called howlite can be dyed to make them look like turquoise. Very large nodules of howlite are mined, slabbed, soaked in dye, and sold as turquoise—sometimes labeled as dyed imitation turquoise.

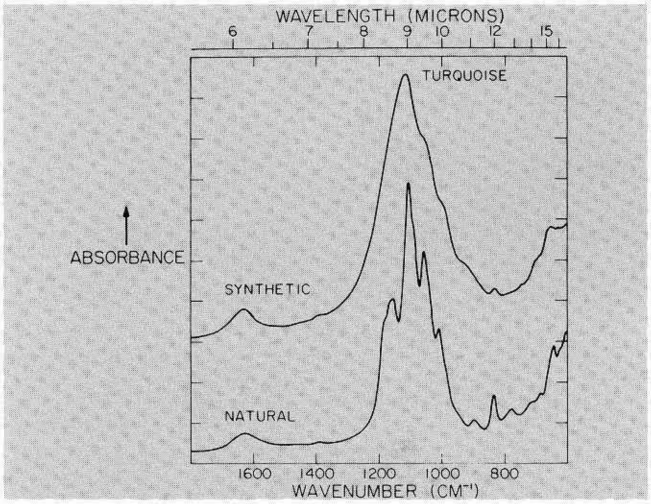


The light absorption pattern makes a diagnostic fingerprint for determining which coloring agent is present in different samples of jadeite.

You can readily tell the absorption pattern of genuine turquoise, using a spectrophotometer. But an even more interesting problem is to distinguish synthetic turquoise, which can be made entirely in the laboratory. It has the same chemical properties as natural turquoise, the color is the same, the density is the same, the hardness is the same. Even the absorption spectrum is the same in the visible region of light absorption. A manufacturer of synthetic turquoise even goes so far as to advertise that there is no way known to man to distinguish it from natural turquoise.

That sort of challenge appeals to me. So I tried to discover a way, and we did it in my laboratory using heat radiation in the infrared portion of the spectrum. We sent different wavelengths of heat radiation through a very small amount of a sample, scraped off the bottom of a stone, and looked at its absorption pattern. In a natural sample, there are several bumps and wiggles in the curve, and the fine structure shows sharp absorption peaks that are diagnostic of the absorption of heat radiation in natural turquoise.

In the synthetic sample, there is the same region of absorption, but the fine structure is relegated to very weak little shoulders on the absorption trace. The same



Infrared radiation passing through natural turquoise shows sharp absorption peaks, in contrast to the smoothed out curve of synthetic turquoise under the same treatment.

pattern appears in all samples of synthetic turquoise that we have examined, so this is a reliable method of distinguishing synthetic, grown-in-the-laboratory turquoise from the real thing.

A more challenging aspect of the field of mineral and gemstone coloration is represented by beryl, which is a comparatively obscure mineral, at least by this name. Chemically it is beryllium aluminum silicate. When no other element is present, beryl is perfectly colorless. But beryl also comes in colored varieties, which have such names as emerald, aquamarine, and morganite. The deep rich green of emerald is brought about by the presence of chromium substituting for a small amount of aluminum inside the emerald. About 0.1 percent by weight of chromium in a plus-three oxidation state is adequate to impart that color.

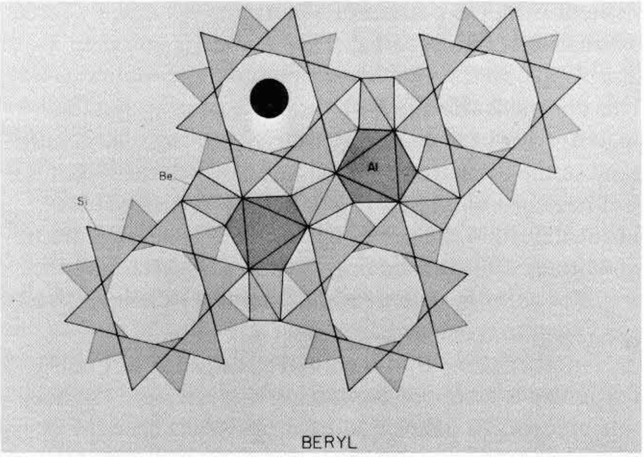
Morganite is a manganese-containing variety of beryl. If the manganese concentration is low, the color is very pale. When it is high, a spectacularly rich deep red morganite results. Unfortunately, it is seldom obtained in pieces large enough to be satisfactory for gem purposes.

A variety of beryl of great interest to me is aquamarine, which contains iron as the chemical impurity that imparts the color. Aquamarine comes in a wide variety of colors—brilliant golden yellow, yellow to yellow-green, and green, for example. The most desirable variety of aquamarine for gem purposes, however, is blue. Blue aquamarine is considered one of the birth stones, and is cut and fabricated into pieces of jewelry. But the chances are that if you have a piece of blue aquamarine, it did not start off life that way. Very early in the history of gems, the miners discovered that if they put their samples of, say, yellow beryl in charcoal stoves and heated them for a few hours, they would change from yellow into an attractive blue color. That is a widely applied very primitive technology.

What is there about the iron in beryl that gives rise to this variety of colors, and how does the application of heat change the color to blue? To answer this, we have to look at the atomic structure of beryl, in which there are three fundamental building blocks. First, there is an atom of aluminum that is surrounded by six atoms of oxygen, arranged in the geometry of an octahedron; second, an atom of beryllium, surrounded by four oxygens in the geometry of a small tetrahedron; and finally, an atom of silicon, also surrounded by four atoms of oxygen, and arranged in a larger tetrahedron. What we have to do is understand how these individual building blocks are assembled inside the crystal to form the structure of beryl.

What happens is that the silicons connect to form rings that stack up on top of each other in such a way as to define a soda-strawlike channel through the length of the crystal, and the iron that causes the color in beryl is located in those channels.

How does the iron inside the channels give rise to the transformation from yellow to blue under the heat treatment? The answer has to do with the oxidation of iron. As it is found in nature, yellow beryl contains a predominance of iron in the plus-three oxidation state;

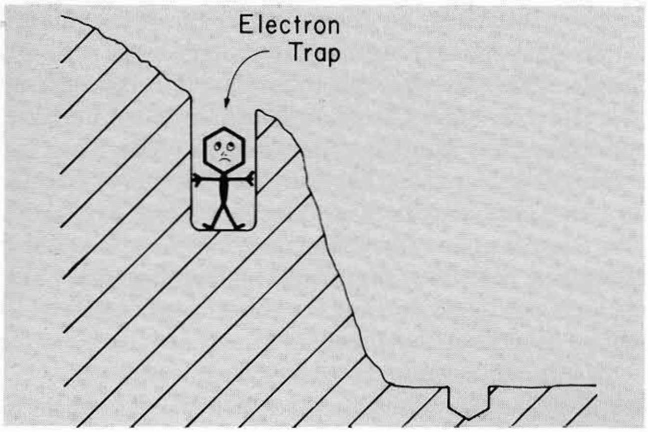


Silicon atoms in beryl form rings that stack on top of each other, forming soda-strawlike channels in the crystal. Iron in those channels causes the color in the mineral.

when the beryllium is heated in the charcoal furnace, the iron located in that channel is reduced to the plus-two oxidation state, gaining an electron and changing its color to blue.

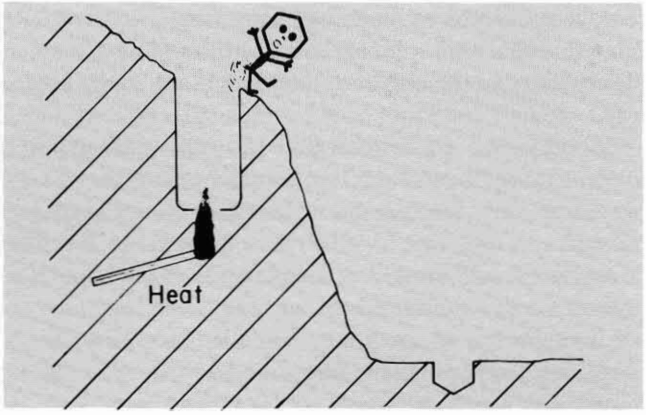
Another example where heat treatment is used in the modification of gem colors is that of zircon. Zircon is a widely distributed mineral. In the chemically pure state it is zirconium silicate. It has value because it can be cut and fabricated into a colorless stone. But it also comes in a wide variety of colors, which indicates that impurities are present. The most important impurities for the coloration of zircon are uranium and thorium in amounts up to 0.5 percent.

Zircon that contains uranium has a color ranging from pale to deep amber-red. If these zircons are heated, some of the samples will become completely colorless, but a small proportion will turn a very beautiful blue, and will stay that color. What is the role of uranium in this process?



When a gamma ray ejects an electron from an atom in a crystal, the electron loses energy and eventually comes to rest in an "electron trap" where it can absorb light and produce color.

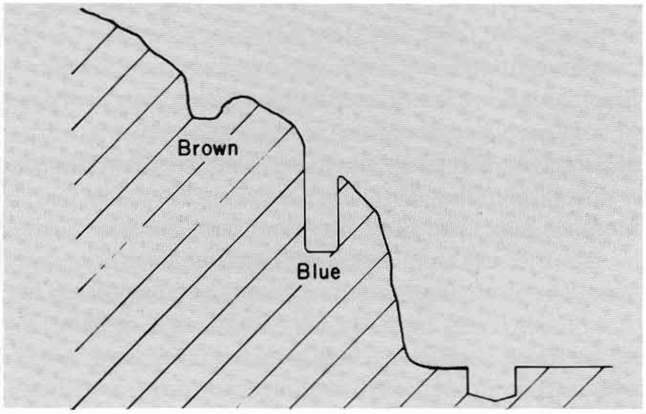
Uranium is a radioactive element, and as it slowly decays over many thousands of years, it liberates gamma rays, alpha particles, and electrons within the crystal. The gamma rays traveling through the crystal are so energetic they can take an electron from an atom of, say, oxygen and physically eject it. This electron will go cascading through the crystal, bouncing off atoms, and slowly losing its energy until it finally comes to rest in what I call an "electron trap." The electron wants to be back on the oxygen, but it can't get out of the trap. Inside that trap it has the ability to absorb light, to produce color within the crystal.



One way to change the color of a mineral is to get the electrons out of the trap by applying heat. If you apply enough heat, the mineral may become colorless.

Technically speaking, what this electron trap may be is the combination of one of the electrons near an adjacent zirconium with some other chemical impurity within the crystal. Another possibility is that an electron may go wandering through the crystal lattice, bouncing off different atoms until it comes to rest in a defect—a missing atom—where it sits absorbing light and giving color to the crystal.

We can get the electron out of the trap with the heat treatment. If you apply enough heat, all the electrons can be totally removed from the traps, and the zircon will become colorless. Very often, however, there are multiple traps, and if an electron is stuck in a particular one, it will impart a brown color to the crystal. If it's stuck in a much deeper trap, it will impart a blue color. If we very carefully control our heat treatment, we can



Often there are multiple electron traps in a mineral. When the brown trap is shallower than the blue, carefully controlled heat treatment may make it possible to keep the blue color.

remove the electrons from the brown trap—because it's relatively shallow—and at the same time we can keep the majority of the electrons where they are in the blue trap.

Spodumene is a mineral found in gem mines in San Diego County, near Pala. It is actually one of the pyroxenes, lithium aluminum silicate. It comes in two colored varieties, one of which is called kunzite. Kunzite contains a small amount of manganese, which imparts a lavender color in minerals. A second, much less common variety of spodumene is called hiddenite. It contains chromium as the impurity, and the color that is imparted is green. A sample of raw kunzite would probably sell for less than a dollar a carat; a sample of gem-quality hiddenite would probably sell for about a thousand dollars a carat. Understandably, there is a significant financial incentive to come up with a technological way of changing kunzite to hiddenite.

I took a sample of kunzite to JPL and irradiated it with cobalt-60 for many, many hours. It soaked up enormous intensities of radiation, but it did not become radioactive. The treatment is as harmless as sending light rays through a sample, but it does send those electrons on the move and into the traps. When I took the sample out of the irradiator, I found I had indeed changed lavender spodumene into green spodumene. This looks like a good deal, because presumably I could sell these stones and make a huge profit. If I do, I had better take my money and leave the country, because this is a gyp. The color of that green stone will spontaneously fade in a matter of a week. It won't fade back to lavender; it fades to colorless.

Well, I got some interesting science out of this. I learned that the color changes have to do with changes in the oxidation state of the manganese. Lavender kunzite starts off with manganese in the plus-three oxidation state. Exposure to gamma rays oxidizes the manganese to plus-four. In the fading process, electrons are gained by the manganese, which goes back to manganese plus-two, which is pale yellow. It's interesting chemistry but very poor economics.

Another example is that of topaz, which is a typically colorless aluminum silicate. In a few places in Utah, the Soviet Union, Brazil, and Mexico, samples can be found that have a lovely amber to cinnamon-red color. These stones constitute imperial topaz, and they are cut to gems.

The color of topaz is induced in nature by the presence of radiation. Everything in the ground has a very small amount of radioactive elements. Over hundreds of thousands of years, crystals of minerals sitting inside cavities in rocks soak up this feeble radiation, generating the color that you see. If you subject a sample of colorless topaz to irradiation, it will change to the color of imperial topaz. But again, you have the problem of fading. I put a sample of irradiated topaz on the roof of my laboratory, and within a day all the color was lost. I put it into the cobalt-60 irradiator, and within half an hour the color was back. So, light is another way to get the electron out of the electron trap.

With topaz, however, the story doesn't end there. For a very small percentage of topaz that is irradiated and then carefully heated, something marvelous happens. It turns blue—permanently. This blue color is extremely desirable for gems; in fact, blue topaz is a gemstone that dates back to ancient times. It is possible to create a blue topaz by an artificial laboratory process, and the result is identical to natural blue topaz. The chemistry is the same, and so are the optical properties, the density, and a variety of other properties. Artificial blue topaz is essentially indistinguishable from natural blue topaz, because in this case the laboratory technician is exactly duplicating the coloring agent that is present in natural blue topaz.

If it is important to do so, how do you tell them apart? Well, this is Caltech, so we took on answering that question as a challenge.

The electron sitting in a trap is really in a site of higher energy than normal. Sunlight or heat has the ability to remove the electron from its trap, but in the process the electron has to dissipate its excess energy. It can do this in two ways. One is to make the crystal warm. Crystals that have been intensely irradiated often feel warm to the hand because of the electrons moving back toward the place they want to be. The second way for the electron to dissipate its energy is in the form of light.

Technically speaking, the electrons in the crystal returning to the site from which they came commonly transfer some of their energy to a small amount of some impurity inside the crystal. The light that you can see is the glow of the impurity, and the name for the phenomenon is "thermoluminescence," that is, light caused by heat. There are ways of observing this glow under carefully controlled laboratory conditions that allow us to utilize thermoluminescence as a method of detecting samples of minerals that have been irradiated.

We place the crystal in some sort of heating apparatus, and we then simultaneously monitor the temperature of the sample and look at the light that is emitted from it, collecting it with a photomultiplier tube, a light detector. A chart recorder takes the signal and makes a graph of the intensity of light given off as a function of the temperature of the sample. If we see thermoluminescence, we know absolutely certainly that the sample has a history of radiation treatment, either in a laboratory or in nature. Furthermore, if a sample of topaz has been heated in a laboratory to a temperature high enough to bleach out the brown color, the low-temperature thermoluminescent electron traps will have been removed in the process.

When we compare natural blue topaz and artificially irradiated blue topaz, we get two distinctly different curves. The natural sample will show thermoluminescence at a temperature somewhat above 200 degrees. But the glow of the artificially heat-treated sample does not begin until a somewhat higher temperature and shows all sorts of different higher temperature electron traps. This is a very simple way of differentiating between artificially treated and natural blue topaz. To do so requires a sample quantity so small that a cut and faceted gemstone can be scraped on its edge to acquire a few grains, and there will be no damage to it.

What about irradiating other minerals? If you irradiate halite, which is common table salt and colorless in nature, it turns amber. If you irradiate it still more, it turns black. This could raise the interesting possibility of serving black table salt, but I don't think anyone intends to use water-soluble salt as a gemstone.

Common old silicon dioxide—sand or quartz—is colorless in its chemically pure state. When either man or nature irradiates it, it turns dark. This is done commercially to form smoky quartz. Natural smoky quartz contains aluminum as an impurity, and natural irradiation develops the brownish-black color. Colorless natural quartz that contains aluminum but has not been subjected to natural radiation can be artificially irradiated to produce smoky quartz, and I've seen it for sale at a variety of places.

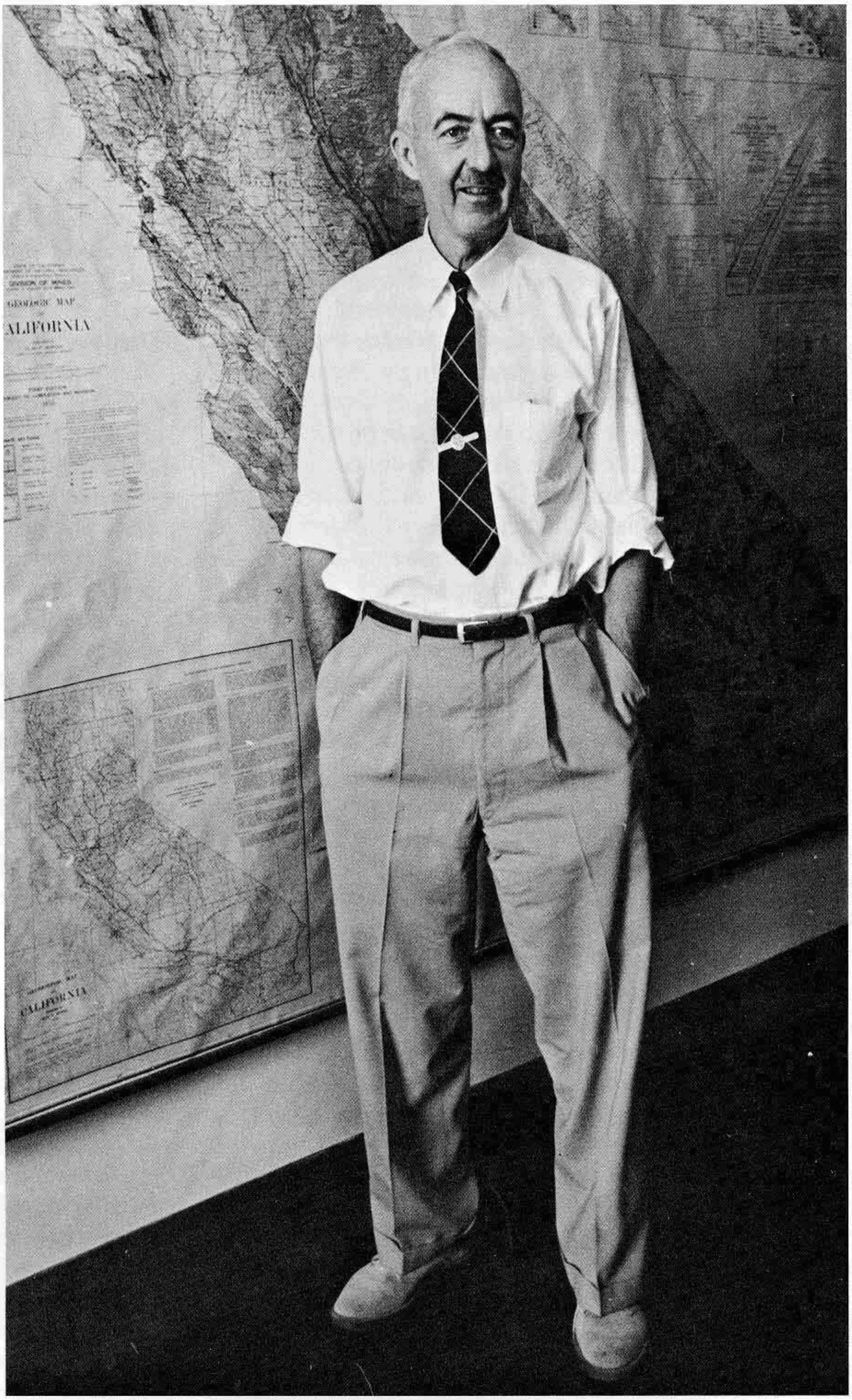
If iron instead of aluminum is the impurity in quartz, treating it will produce amethyst, but because of the abundance of amethyst in nature, there's no economic incentive to produce it artificially.

Rubies and emeralds are not subject to radiation treatment in the laboratory. You get them naturally and that's it. Both, however, are readily synthesized in the laboratory. Sapphires are also readily synthesized, so there's no economic incentive to do radiation coloration. A small amount of heat treatment is occasionally used to enhance the color of blue sapphire. Yellow varieties of sapphire can be spectacularly enhanced in color by radiation, but they quickly fade. This is surprising because natural yellow sapphires are perfectly stable.

You've probably been led to believe that diamonds are colorless, or at best blue-white. This is the result of advertising by the gem industry. Diamonds come in a variety of colors—yellows, blues, reds, greens, and all sorts of intermediate shades. Irradiated diamonds are things of beauty. Is the color stable? Well, we all know a diamond is forever.

This again brings up the question of whether synthetic or artificially enhanced minerals are gems or gyps. Obviously, if a product is misrepresented, it is a gyp. And in the area of fine gems purchased as investments, the need for caution is great. Fortunately for the consumer, the reputable gem industry is deeply concerned with its image and its integrity. The industry maintains its own research programs into methods for establishing the origin of color in gems and makes frequent use of the type of information scientists generate in their study of minerals.

Materials that are not of investment caliber must be considered as a separate case. Such materials would be purchased primarily for their beauty, and in this case the value is in many ways subjective. For the person who demands only natural color, and is willing to pay the price, sufficient safeguards have been developed generally to protect the customer. But as the demand for gems increases, the supply will become depleted and the costs will rise. It is here that technology can increase the supply and keep costs down by transforming ordinary minerals into items of beauty. The scientists who design these processes are concerned with producing valuable products that will be acceptable to the public, and their products are absolutely indistinguishable from naturally colored stones except by methods available only to specialists. The beauty, color, and durability of such technologically produced gems are equal to, and in some cases superior to, naturally colored stones. In fact, the lab technician is generally duplicating in minutes the exact processes that nature takes tens of thousands to millions of years to accomplish. My own answer to the question is that these are indeed gems. ☐



Recollections of Ian Campbell

by ROBERT P. SHARP

Ian Campbell passed gently from this earthly scene at the age of 78 on February 11, 1978, in San Francisco, a victim of a quiet but valiant fight with cancer over a dozen years. Others will write of his awards and professional accomplishments during 28 years as professor and administrator at Caltech and a decade as State Geologist and head of the California Division of Mines and Geology, and of his stewardship of countless committees, his leadership of professional societies, and his many, many public services. My aim here is to illuminate some aspects of his character by means of personal recollections and observations.

We arrived at Caltech at about the same time, but in totally different capacities, he in 1931 as a new assistant professor in Geology and I in 1930 as a freshman. It was one of the pleasures of my life to have been his student and eventually his close friend and colleague during the succeeding 48 years.

Ian's outstanding characteristic was his warm, unselfish, devoted service to others. This trait surfaced early when, presumably by being a little vague about age, he was able to enlist in World War I and saw duty with the 361st Ambulance Company of the 91st Division along the northern front in France and Belgium. He must have been barely 18 when the armistice was signed—an event at which he was present and by which he was deeply impressed. Down inside Ian was a much freer spirit than his usually decorous conduct would suggest. As a young man he loved motorcycling and the free openness of that mode of travel. The Harley-Davidson Company once awarded him a medal for traveling by motorcycle from Portland, Oregon, to Portland, Maine.

When he and his wife, Kitty, a professional geologist in her own right, first came to Pasadena, they lived in a small backyard house just north of the Huntington Hospital. I had a particular fondness for the student nurses of that hospital in those days, so I had occasional first-hand reports on Dr. Campbell's conduct. My informants told me that during the 1933 Long Beach earthquake Ian ran shouting from his house, not in fear but with excitement over the occurrence of this powerful natural phenomenon and its scientific implications.

Ian Campbell *californicus,* an appellation affectionately bestowed by one of his close faculty associates, was an incorrect designation. It should have been Ian Campbell *oregonensis,* for he was an out-and-out Oregonian. Ian grew up in the state and loved every aspect of it, passionately. I once aroused his ire, during a fall-season trip through Oregon, by asking if the red berries on a mountain ash were Oregon cherries. He let me know in no uncertain terms that Oregon cherries were at least three times larger and twice as red, besides being deliciously edible. His father, Dugald, was an early cherry grower in the Eugene area. Ian had friends and friendships all over the world, but some of his warmest relationships were based on early Oregon associations.

Ian was an indefatigable letter writer, often with multiple copies to all concerned. Legions of graduate students with degrees in geology from Caltech will tell you emphatically that the sole reason they came to Caltech was a letter from Dr. Campbell. Each missive was a highly personal, carefully crafted effort that completely outclassed the form letters of other colleges and universities. Students were one of his prime concerns. Once they were admitted to Caltech, he taught them well and ministered to their other extracurricular needs with care and devotion. No one could handle the problems of draft deferment more expeditiously, yet wholly properly, than draft-board member Campbell. He knew the system inside-out from work on Selective Service Board 190 from 1940 to 1946, and his chairmanship of Board 92 from 1948 to 1959. He always provided a sympathetic ear to other student woes and problems and was unusual in his follow-up action on such matters.

One of the problems about the many Campbell letters and notes was the atrocious handwriting. It is reputed that only two people in the world could really read it, Norna Reno, long-time secretary of the Caltech Geology Division, and wife, Kitty. Even Kitty sometimes had trouble. One summer my wife, Jean, motored from the Midwest with Kitty and young son Dugald. Ian was somewhere abroad, as I recall. Each evening on the trip Kitty would take out Ian's latest letter to puzzle over a few remaining undeciphered words just to be sure she wasn't failing to act upon some request Ian had made. Most of us could generally make out the main gist of a Campbell note, but we were often unsure as to whether we were to go or stay, turn right or left, or do nothing. Fortunately Ian used a typewriter whenever possible.

One discipline I learned from Ian was to write postcards while waiting to be served at a roadside cafe during travels. He always had a shirt-pocket full of cards; they were a penny each in those days and obviously appealed to his Scottish sense of thrift, and to mine too. I have often speculated about the greater pleasure experienced by recipients of Ian's cards, as they slowly and haltingly unlocked the secrets of his message, compared to the casual glance given a card written in clear handscript. People are fascinated by puzzles, and his cards were puzzles with infinite appeal that could be worked on for days.

The Campbell Christmas party was always one of the outstanding events of the holiday season. It came in two parts. In the late afternoon a gathering was held for staff, faculty, and old friends. The evening of the same day was devoted to the party for students. Of the two installments, one always had the sneaking suspicion that the Campbells enjoyed the student party more. After eating and drinking everything in sight and staying way beyond any reasonable hour, the students departed with a feeling that someone truly cared about them.

Ian was very good at combining fun and games with work. He enlivened the laborious, almost deadening, chore of measuring the amount of mineral phases in rock thin sections by inventing a competition known as the "micrometric sweepstakes." The winner of this prize was announced with great flourish and high-flown oratory at the annual spring petrology party in the garden of the Campbell home on South Bonnie Avenue in Pasadena. On the same occasion the winner of the hand-specimen contest was also honored. This was Ian's contribution to the nearly lost art of fashioning decent hand specimens in the field. They were inspected with exquisite care as to shape, size, evidence of misplaced hammer blows, and sophistication of geological features represented. Many of the best of these specimens, and some were very good, repose to this day in showcases in the Arms Laboratory. The micrometric sweepstakes, the hand-specimen contest, and that annual petrology party linger fondly in the memory of many, many Caltech graduates.

Occasionally of a late afternoon Ian might appear at the office door of a student or faculty member with an unexpected invitation to engage in a little game of darts. In a state of wonder, the invitee followed the host to the subbasement of Arms Laboratory, and there in all its splendor in semidarkness on the side of a rock-storage cabinet was a dartboard. Few people could trim the canny Scot at his own game, throwing darts in the gloom. With sympathetic and gentle words for the stray shots of his competitor, Ian quickly demonstrated who was the better thrower.

Allied to the sense of fun was one of the more remarkable Campbell traits, that of blunting an antagonistic confrontation by illuminating the humor of the situation or turning the whole thing into a joke. While some of us might fume over the irritating actions of an associate, Ian always saw the amusing side of the affair. An irritating action became the source of a chuckle for him, which he readily shared with others. This facility must have been one of the reasons he lived long and happily.

Although conservative in dress and behavior, he was remarkably liberal in politics. One can suspect that he even occasionally voted for Norman Thomas as a way of expressing discontent with the prevailing political scene. Ian fought for various causes, large and small, with sustained ingenuity, endurance, and tact that often won the day. It was under his stewardship that the headquarters of the Geological Society of America, of which he was then president, moved from its traditional headquarters in New York City to the fresh open spaces of Boulder, Colorado. This was like opening the windows and turning on the lights in a room too long tightly closed and shrouded in darkness. He was the innovator of many changes in the California Division of Mines (and Geology) during his tenure as State Geologist. Most Caltech gentlemen now lunching in open shirted comfort at the Athenaeum are not aware that it was the dogged, continuing effort of Ian Campbell that eventually led to the abolishment of the coat-and-tie requirement for the noon meal there. Even the matter of Dick Jahns' mustache could be a subject of Campbell advocacy, a struggle he won over formidable opposition from Dick's wife, Frances.

Ian was deeply proud of his Scottish heritage. When traveling or camping with him, you ate your breakfast porridge (oatmeal) without sugar. Sugar spoiled the taste. He welcomed the various "Macs" to Caltech with special warmth and gusto, although their ancestors may have slaughtered the Campbells in the Highlands years ago. They were, after all, Scotsmen. He saw to it that the officers of the Geological Society of America, at their annual national meeting in Los Angeles in 1954, were escorted to their places at the head table by a kilted bagpiper. It is even rumored that unearthly noises occasionally ascending from the subbasement of Arms Laboratory came from his own bagpipes. He was a Scottish spartan in terms of his own wants, but he was generous beyond words to others.

Only once in my career was I irritated with Ian. It happened during my PhD oral examination at Harvard, and he wasn't even there. The venerable Charles Palache, professor of mineralogy, handed me a piece of paper that showed a collection of dice with various markings on their faces. He asked if I had ever seen it before, and when I said no, he was pleased. He explained it was from a quiz Dr. Campbell once gave to a class at Harvard while working as Palache's assistant. Palache then proceeded to grill me on the crystallographic symmetry elements of those dice. I performed poorly, all the while silently cursing that diabolically clever Scotsman, Campbell.

The students, staff, and faculty at Caltech never had a truer, warmer, more devoted friend than Ian Campbell. Integrity, devotion, sincerity, good humor, patience, tolerance, compassion, kindness, humility, and industry are all words that come to mind when one thinks of the man. Generations of Caltech students will remember him as the one who made the rigors of a Caltech education not only bearable but an enriching experience. In Ian's own words, "There are many ways to serve," and in my words, "Ian Campbell exercised more of those ways than any other person I have ever known." He loved his fellow beings, and in turn was deeply beloved and respected by them. □

The Ian Campbell Graduate Fellowship in Petrology

In memory of Professor Ian Campbell, the Division of Geological and Planetary Sciences has taken the initial steps to establish an Ian Campbell Graduate Fellowship in Petrology, which will enable us to provide support for students concentrating their work in the broad area of geological sciences that Ian so ably fostered at Caltech and that remains a central field of research and study in the Division. An endowment fund to support the fellowship is being sought, and contributions in Ian's memory are invited.

Barclay Kamb, *Chairman*
Division of Geological
and Planetary Sciences

Solar Energy

. . . continued from page 11

world affairs that we have so far in the 20th century.

The third barrier to the introduction of solar energy is the pricing policies of the utilities. Utilities are, in fact, controlled by the elected officials of the states. They are not run by a Machiavellian group of top-hatted, fat business men from Wall Street, but by a bunch of people representing the regions in which they live. They reflect the attitudes of the people who run those states. Their present attitudes, for various reasons, do not tend to encourage—and in some cases tend to discourage—the introduction of solar energy. For example, in the case of gas, or any other resource which needs to be conserved, there should be a rate system that reflects the fact that as you use more, that extra increment of gas costs a lot more. Such a price structure would provide an incentive for developing alternative technologies to avoid having to use that extra gas. Solar-assisted gas water heating would look a lot better under that kind of pricing structure, for example.

The state of California has already made some rather radical changes, including an inverted electrical rate structure, a conservation measure to decrease consumption. Because it taxes the big guy a lot more than the average homeowner, it's an easy political adjustment to make, and it is not surprising perhaps that it is one of the first radical departures from previous policies by the state of California. However, I am hopeful we may see other enlightened changes as well.

I think we will see a lot of differences elsewhere in the country. Some states are going to make it, and some are not. It has happened before. Vermont and New Hampshire used to be leading industrial centers for the United States (using hydro power). They are not now. The South used to be impoverished and downtrodden. It is not now. Some parts of the country are going to get better; some are going to get worse. And it's going to have a lot to do with how intelligently they deal with future energy supplies and current utilization patterns.

There are other important aspects of utility pricing. For example, to produce electricity from the sun on site—at schools, hospitals, factories—arrangements must be worked out for electricity generated to be sold to the utility when it is not used on site, say on holidays and weekends, or when there is otherwise excess capacity. Similarly, the same utility must be able to provide base load at other times. Hence, sometimes the excess electricity will have to flow the "wrong" way down the wire, back into the utility company, where it can be distributed and used elsewhere instead of fossil fuel plant production. That means the utility companies have to buy it back from you. Right now they have so little incentive that the amount they will pay is unrealistically low. This is a complex technical and regulatory question, but I am optimistic that a suitable incentive system for both the utility and its customers can be arranged if the people of a given region place priority on such an objective.

A fourth barrier to the introduction of solar energy is that solar energy equipment is usually expensive when first purchased. If you want to put in a solar heating system, you have to pay nearly all the cost at the beginning to pay for the equipment. The benefit comes in reduced gas and electrical bills later on. On the basis of "life cycle costing," it may well be quite advantageous, but the average homeowner may not be able to handle that initial investment. So one approach, at least in California, could be to have the gas company lease to you, at a standard monthly charge, the equipment that is required for solar water heating, for example—or maybe for solar space heating, in time. Let the gas company deal with the bankers. Let it deal with the maintenance and the obsolescence of equipment, and let the cost show up as a fixed increment on the monthly bill. That way the utilities, rather than being a barrier to new technology, could be an essential attribute to its introduction. This also is a complex issue because of the many factors the utilities must consider. But it is an option if the society wishes to create appropriate regulatory and tax incentives.

The United States came out of the 1960's deeply polarized and with a profound suspicion of institutions, particularly large institutions. It is ironic that some of the strongest advocates for solar energy are also the most suspicious of large institutions. They are convinced that the large oil companies and the utilities are making a rip-off and that the nuclear industry has the government in its pocket. This very suspicion may do more to inhibit the development of solar energy than anything else, because I feel we have to use the large institutions to get the solar technology in place. We have to involve the utility, rather than make it feel threatened and defensive by the advent of solar energy. Letting the utilities be the institutions to introduce solar energy might well be the most successful way to enhance development of solar energy.

Finally, in listing barriers to the introduction of solar energy, there is the fact that in the building industry there is considerable inertia from labor unions, building codes, permits, etc. A lot of solar energy activity involves both retrofitting old buildings with new equipment as well as incorporating it in new buildings as they are constructed. These techniques require society to overcome a tremendous inertia. It is not because of a negative vested interest. It is not conspiratorial. But people are accustomed to doing things in a certain way. They have specialized skills. They are trained to use them. The changing of that, to introduce something on a large scale like solar water heating, space heating, and electric generation built into buildings, is going to take a lot of time.

I'm not optimistic that change will occur very rapidly unless we can provide positive incentives to the various groups and factions to evolve their ways of doing things. Then the progress could be much more rapid.

SUMMARY

Solar energy utilization in ground systems probably will come in initially as supplements to existing gas and electric systems, and will continue as a part of the energy infrastructure indefinitely in a mixed form. It is not a question of solar *instead* of nuclear, or solar *instead* of coal exclusively. It's a question of what the mix will be, and the solar part of the mix could be quite large. A lot of the deleterious side effects of nuclear and coal could be minimized by bringing in a large component of solar. But it will have to be brought in in a harmonious, synergistic way, not as competing and separate.

If energy—especially electrical energy—becomes not just expensive, but just not available, then solar electric will look particularly attractive. Similarly, if gas were to become just not available, solar water and space heating will look very attractive —almost regardless of cost.

I think some of that is going to happen.

Second, if the society will allow the price of energy, including natural gas, to rise to its replacement cost, the introduction of solar and other new technologies will be greatly expedited. The longer this is delayed, the more difficult it will be to introduce solar. That is a politically tough thing, because everybody pays a gas bill, everybody pays a fuel bill, and a higher bill will not be politically popular. But I feel very strongly that it is in the best interests of our children and our children's children to add a substantial solar component to the total energy mix.

It must be recognized that there *is* a cost trade-off; it *will* mean a higher utility bill to have cleaner, safer energy. It doesn't do any good to use political rhetoric implying that that is not true. It means a trade-off in standard of living. It's a question of the quality of one's life in terms of amounts of material goods versus the quality of one's environment.

I believe the energy problem is going to force this society to face that issue more starkly than any other single circumstance in the coming decades.

Third, the introduction of solar energy will be aided by the constructive evolution of institutions, such as utilities and energy companies, to be part of that process, rather than threatened by it. This, again, is a political problem. It's a case of building an understanding and a partnership among groups of people who right now are not very close together. It's a political challenge, and it can be solved. It also might *not* be solved. The outcome will have a lot to do with how effectively solar energy actually gets into people's homes, into their schools, and their shopping centers.

A fourth conclusion is that solar energy can fit into both a centralized energy society, as we have now, or a more dispersed one. Many energy alternatives cannot. California is particularly well matched to the introduction of solar energy, and therefore it makes sense for California to take an aggressive posture toward the introduction of solar energy. It is in our own self-interest and may well aid the country's future as well.

A fifth conclusion is that whether or not ground solar-electric generation makes sense, the economics of space solar-electric clearly are a long way in the future. Because it has some unique merits, the major technological bottlenecks that make the costs so high should be delineated and a program initiated aimed at their reduction. But I don't think we should look upon space solar energy as a practical element in our future or even that of our children.

The final conclusion then is that solar energy is not *the* true god in the sense that it is clearly *the* solution; it is also not a false prophet. It isn't an illusion. It *could* be a primary energy source for the United States a lot sooner than any of the predictions that you see. But it will not happen by marketplace forces alone. It will not happen if we are divided and polarized, as has been the case with nuclear; that will kill effective solar energy development, I feel. The threat is that we might, as a country, find ourselves with no choice but to go along with high-pollution forms of energy in the future and rule out the benefits that solar might confer.

You can see, therefore, that so far as solar energy is concerned, I am not a Deist, I am not a Theist, but rather I am an Existentialist. Society is going to create its own god in this situation, its own religion. We will, in fact, choose our own pathway. It is open to us to go on a relatively high solar road. It is also open to us to go on a "lower" coal road. What will happen will reflect the preferences, expressed one way or another, of the people of this country regarding their environment, their health, their material standard of living, and their attitudes toward their descendants. ☐

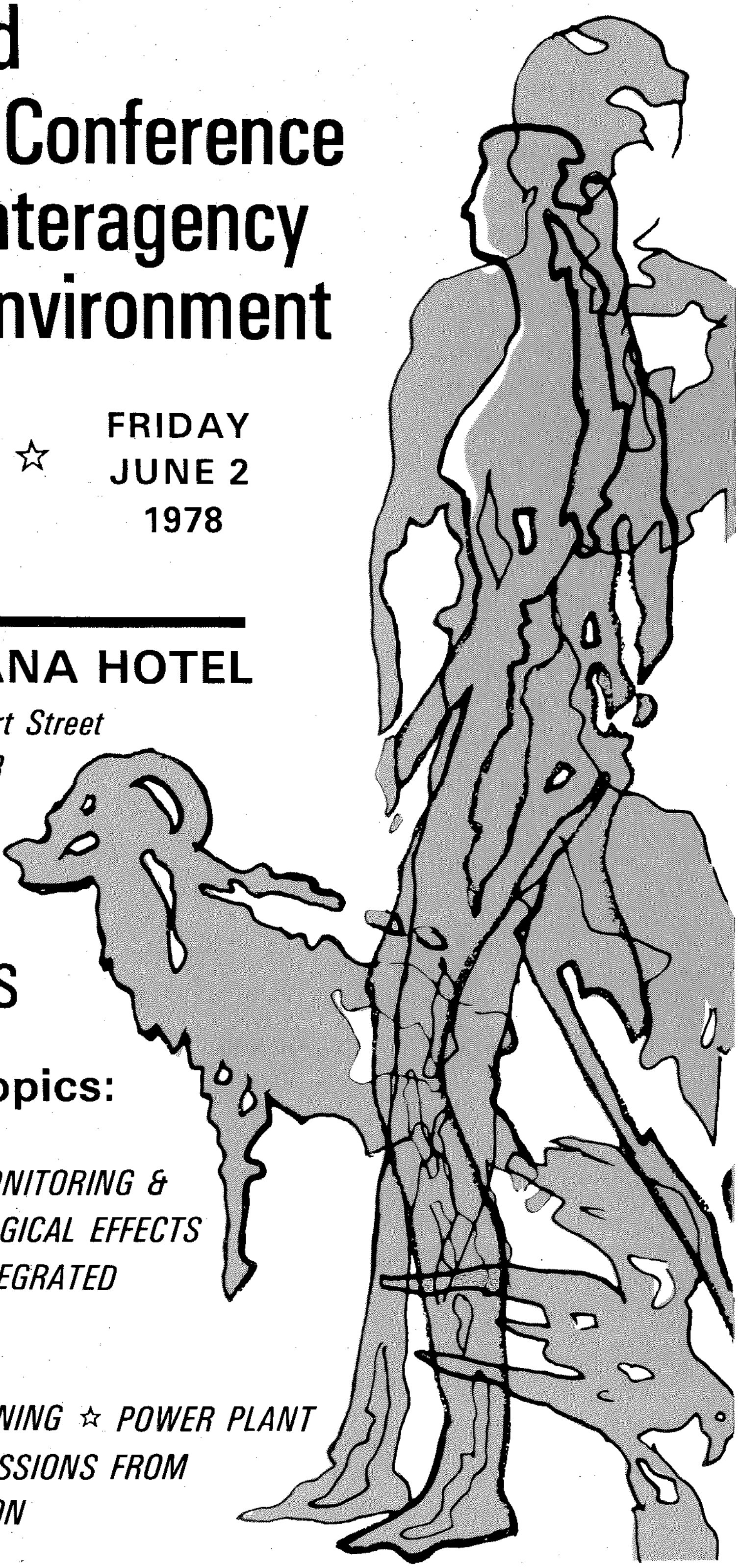
Environmental Protection
Agency Office of Energy,
Minerals and Industry

The Third National Conference on the Interagency Energy/Environment R&D Program

THURSDAY
JUNE 1
1978

☆ ☆

FRIDAY
JUNE 2
1978



SHOREHAM AMERICANA HOTEL

Connecticut Avenue at Calvert Street
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TECHNICAL DISCUSSIONS OF SELECTED RESEARCH AND DEVELOPMENT ACHIEVEMENTS

Selected Conference Topics:

Thursday, June 1, 1978 Sessions 9am - 5pm

HEALTH EFFECTS OF POLLUTION ☆ MONITORING & TRANSPORT OF POLLUTANTS ☆ ECOLOGICAL EFFECTS OF COAL-FIRED POWER PLANTS ☆ INTEGRATED TECHNOLOGY ASSESSMENT

Friday, June 2, 1978 Sessions 9am - 5pm

CONTROL TECHNOLOGY: ☆ COAL CLEANING ☆ POWER PLANT WASTE DISPOSAL ☆ CONTROL OF EMISSIONS FROM COMBUSTION ☆ MINING RECLAMATION

CONTACT: Coordinator

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